EGYPTIAN IRRIGATION

SECOND EDITION

احمد راغب

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EGYPTIAN IRRIGATION

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BY

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WITH AN INTRODUCTION BY

MAJOR HANBURY BROWN, C.M.G., LATE R.E.
INSPECTOR-GENERAL OF IRRIGATION, LOWER EGYPT

ANCIENT SYSTEM OF IRRIGATION.

"Thus they do, sir: They take the flow o' the Nile
By certain scales i' the Pyramid; they know,
By the height, the lowness, or the mean, if dearth
Or foizon follow: The higher Nilus swells,
The more it promises: as it ebbs, the seedsman
Upon the slime and ooze scatters his grain,
And shortly comes to harvest."—*Ant. and Cleo.*, ii. 7.

MODERN SYSTEM OF IRRIGATION.

"Naturam furcâ expellas, tamen usque recurrit."

SECOND EDITION

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1899

Dedicated

TO

H.E. THE LATE NUBAR PASHA, G.C.S.I., G.C.M.G.,

FOR MANY YEARS PRIME MINISTER OF EGYPT, AND THE AUTHOR OF THE WELL-KNOWN SAYING THAT "THE EGYPTIAN QUESTION WAS THE IRRIGATION QUESTION."

It was due to him that at a time of great financial difficulty, and in the teeth of much opposition, the money was found to initiate the repairs of the Barrages and test the practicability of abolishing the corvée.

This book is a confirmation of his saying that if the Delta Barrages were made capable of doing their duty and the corvée were abolished, the treasury would never again find itself empty. The former would ensure the waters of the Nile entering the canals, while the latter would permit of the fellaheen being in their fields and utilising these waters to the utmost.

PREFACE

TO

THE SECOND EDITION.

TEN YEARS have elapsed since the First Edition was written; and it has become necessary to publish a Second, and to bring the information up to date. My best thanks are due to Major BROWN, C.M.G., who has consented to write the Introduction, and to the officers of the Public Works Department, who, with the kind permission of SIR WILLIAM GARSTIN, have freely supplied me with all the information at their disposal. To Mr. CLINTON DAWKINS I am indebted for most of the interesting information about the land revenue of Egypt, contained in pages 386, 389 and 390; and to Dr. SCHWEINFURTH, Mr. FULLER, C.I.E., and Mr. ERNEST FLOYER for information about the Upper Nile and the nitrate question.

W. WILLCOCKS.

CAIRO: *January 1st*, 1899.

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INTRODUCTION.

BY MAJOR R. HANBURY BROWN, C.M.G., LATE R.E.,
Inspector-General of Irrigation, Lower Egypt.

So far as his contemporaries are concerned, neither Mr. Willcocks nor his book requires an introduction in the ordinary sense of the word. For the book, the first edition, much appreciated as it has been, is the best introduction to the second. As for the Author, no European is better known to all sorts and conditions of men in Egypt from the First Cataract to the sea "from Migdol to Syene." But though the present generation is not likely to forget who he is and what he has done, we must take thought for the future when a new generation will arise that knows not Willcocks, but for whom the book will survive and the Nile still flow. "For men may come and men may go, but I go on for ever." For those that come when we have gone, it will be an advantage to have the means of forming a just estimate of the Author's claims to be accepted as an authority on the subject of Egyptian Irrigation; and they will be better able to decide how far to trust themselves to the guidance of what is written, if they know the extent of the opportunities of acquiring correct knowledge enjoyed by him.

Mr. Willcocks, after distinguishing himself beyond his fellows as a student at the Thomason Civil Engineering College, Roorkee, and passing out brilliantly, made his mark in the Irrigation Department of the North-West Provinces of India, and gained much useful experience during eleven years' service. In 1883 he came to Egypt, leaving India, where he was born, for the first time in his life. He was one of the pioneers in the work of causing order to evolve out of the chaos in which Sir Colin Scott-Moncrieff (then Colonel Moncrieff) found the Irrigation Service of Egypt.

During the fifteen years that have followed, Mr. Willcocks, like Joseph of old, has gone throughout all the land of Egypt, and gained a comprehensive knowledge of the country, and the condition of its irrigation and agriculture, such as few, if any others, have. He was the first to discover that the Barrage was wrongly classed with the incurables, and to demonstrate that its shattered constitution could be restored to a sufficiently sound state of health to enable it to do its appointed work, a revelation that has had in the sequel beneficial results to the country of first magnitude. As Inspector of Irrigation of the Central Provinces of the Delta, his energy and enthusiasm astonished all with whom he had to do. And it was while he was our Inspector that he took the lead in introducing and carrying out the experiments which paved the way for the abolition of the corvée—a reform also of first magnitude. During the exceptionally low flood of 1888 he had the good fortune to be told off to accompany and advise the Ministers of Public Works on a special mission, undertaken to consider measures for meeting the difficulties of the situation; and it was on this mission that he became the hero of the account, given in Milner's 'England in Egypt,' of an English irrigation officer being invited to join and taking part in a Mohammedam thanksgiving service in a mosque at Tahta. This mission gave him a clear insight into the conditions of basin irrigation.

Afterwards, as Director-General of Reservoirs, he conducted the studies which led to the decision to make a reservoir above the First Cataract; and he drew up the designs and estimates according to which the Assouan dam and the Assiout Barrage are to be built; projects which may well be described also as of first magnitude.

Finally, he was entrusted with the task of ascertaining the rental value of all land in Egypt, with the object of obtaining figures on which a re-assessment of the land tax could be based, a mission that must have taught him much about the country, and the results of which will not improbably form the foundation of another desirable reform, also of first magnitude.

Such an environment of work, acting on natural ability to assimilate knowledge and to profit by experience, has fitted Mr. Willcocks in an exceptional manner for becoming an author of unusual authority on the subject of Egyptian Irrigation.

And here, before I pass on from the Author to his subject, I would register the regret of Egypt on the loss of a once prominent figure in the Irrigation Department, who came to the country from India in the same

year as Mr. Willcocks. Colonel Ross is not here to write the Introduction to this second edition as he did to the first. A few years ago he went home to die in England, but he had first left his mark on the Southern Provinces in works that have become generally known as "Ross's Sharaki Works," on which, during his last few years of service, he exhausted his failing powers so completely that he never enjoyed health again. And his works, among which his name still lives, were not, like those of ancient Egypt, useless monuments of stone to enclose the forgotten dead, but modest canal works to carry and distribute life-giving waters to a thirsty land.

The second edition of 'Egyptian Irrigation' has the advantage over the first edition of having been written with the fuller knowledge of the country, that has been since gained in many directions. The studies of the different reservoir projects, conducted under Mr. Willcocks himself, as Director-General of Reservoirs, the Geological Survey, under Captain Lyons, R.E., the Protectorate of Uganda, and the Soudan Campaign, have given us new or more perfect information about the Nile beyond the limits of Egypt proper, and about the desert outside the Nile valley. And of Egypt proper and its irrigation we have the fuller knowledge that the experience of ten more years has given, and the printed record of it in the annual reports.

In 1883 and 1884, when Sir Colin Scott-Moncrieff was organising the Irrigation Department, the first thing his staff had to do was to arrest decay and prevent things going from bad to worse, at the minimum expenditure possible, and with no records of past experience to guide them.

Next, as knowledge increased, what was bad had to be made good; and the Western practice of repairing existing works was one of the first novelties introduced to take the place of the Eastern practice of letting works, once constructed, take care of themselves. Ruins of earthworks and masonry buildings were restored, and made to perform their duties; hopeless wrecks of native inspectors and chief engineers, unfit for the open sea of profitable service, were towed into port and left there. The native officials of the subordinate staff, who survived the stress of reform, learnt that they were paid for work; and they also were made to perform their duties and move about their districts—another startling novelty.

Then, when fuller experience of the country had been gained by the

new reformers, came the period of remodelling and making crooked ways straight, both materially and morally: defects (by no means all) in the system of canals and drains were removed, the cross-section and grading of canals and banks were adapted to their objects, and extensive alterations to masonry works were carried out to make them work with more efficiency and less expenditure of human labour.

And, at last, when the Nile supply had been made to do the maximum work that could be got out of it, and the beneficial effects of repairs of works, remodellings of canals, perfecting of the means of regulation, and just distribution of water had been made evident in increased crops and general prosperity, and there seemed to be little for the matured experience of the reformed Department to operate upon within the limits imposed by the ordinary budget allotments, a new prospect of development was opened in a vista of new works. Large sums of money were given by the commissioners of the Caisse de la Delta from the general reserve fund for extending the drainage system of Lower Egypt; the same body in 1898 granted L.E. 530,000 to be spent in a period of four years on two new weirs to be built below the old barrages; and in the same year, a financial arrangement and contract were concluded in virtue of which the Assuân Dam and the Assiût Barrage are to be built within the next five years.

The foregoing is an outline of the course of development of Egyptian Irrigation during the period in which the Author's experience was collected. Probably no period of fifteen years, not even during the most progressive times in the reigns of the Amenemhats and Usertesens of the Twelfth Dynasty, has had such a creditable list of irrigation achievements on record.

With the materials that have been collected during this period in the hands of such an experienced workman as I have shown the Author to be, it was a matter of course that the resulting work on Egyptian Irrigation would be of high value, not only to the members of that Irrigation Department to which a short time ago Mr. Willcocks belonged, but also to those outside of it, whom he has lately joined.

But we live in a scientific and critical age, which teaches us to accept nothing on authority, and *a fortiori* no authority as infallible. And the reason for my "but" is this. I do not agree on all points with Mr. Willcocks. He has paid me the compliment of asking me to write this Introduction because I have had charge personally of both Upper and

Lower Egypt and am, Mr. Willcocks thinks, in a position to criticise and judge what he has written. Such being his express reasons for asking me, I presume I am in order if I point out wherein I differ from him, at any rate in matters that bear on our present and future operations, about which it is important to the country that the conditions which we accept and act upon should be the best possible. And, moreover, the Author has deliberately challenged Macduff to "lay on."

His book, however, is not a book of one man's view, for he has quoted largely from the now considerable mass of reports written during the last fifteen years by those who were his colleagues in the Irrigation Service. Generally speaking, there is agreement as to what are the desirable results to work for, but there is often difference of opinion as to the best method of obtaining those results. Mr. Willcocks has naturally expressed his own views, but he has also paid due respect to the views of others by quoting them in their own words. The reader is thereby paid a compliment and credited with the power of arriving at a decision "when doctors disagree" by the exercise of his own private judgment.

There is some difference of opinion between us regarding the subject dealt with on pages 173 to 175 of Chapter VI. Mr. Willcocks gives the reader to understand that there is much damage being done in Lower Egypt by maintaining high levels in the canals in winter and summer. When this danger signal was hoisted some years ago, I had two maps made up by the Inspectors of Irrigation to show the areas irrigated respectively by free flow and lift at different seasons of the year, one map to refer to the time preceding the restoration of the Barrage, and the other to the time succeeding it. The conclusions drawn from a study of these maps were that the increase, since the Barrage restoration, of the areas of winter and summer *flush* irrigation was decidedly small; and that "heavy and high level irrigation throughout the year" was limited to comparatively small areas under exceptional conditions, of which the most notable instances are the Wadi Tumilât in Lower Egypt, and the Salakûs lands in Middle Egypt. Hence it sounds to me like exaggeration to say that "over hundreds of thousands of acres" are affected by the results of such irrigation.

Further, I cannot reconcile the statements made on page 175 with the facts that a given quantity of water now irrigates a larger area of crop than it used to do; that the average price of land has risen; that the land tax is collected without difficulty; and that the cotton crop

has enormously increased. In support of my facts I give the following extract from a note addressed by the Domains Administration to the Council of Ministers on the 23rd February, 1899.

"Lors de la conclusion de l'Emprunt Domainal, la valeur des terres données en garantie était très inférieure au montant de l'emprunt. Aussi, lors de l'établissement du premier cahier des charges, en 1883, les Commissaires des Domaines durent attribuer aux terres, non pas leur valeur vénale réelle, mais une valeur en rapport avec le montant de l'emprunt dont elles étaient la garantie.

"L'écart entre ces deux valeurs était si grand que pendant dix ans, c'est à dire jusqu'en 1888, les ventes furent insignifiantes.

"En 1888, lorsque le gouvernement procéda à l'échange des pensions contre des terres, il reconnut lui-même que cet écart était au moins de 20 pour cent, et pour faciliter l'échange, il prit à sa charge cette différence.

"Depuis lors, la prospérité du pays s'est développée et la situation, que nous venons de signaler, s'est renversée.

"Nous sommes aujourd'hui en mesure d'affirmer que la valeur vénale des terres restant entre nos mains est supérieure de 20 pour cent au solde de l'emprunt domanial, bien que la valeur des produits ait baissé depuis 1888 de plus de 50 pour cent."

There is, however, agreement as to the existence of land damaged by infiltration, though not as to its extent nor as to the remedy to be applied. Mr. Willcocks recommends (p. 175) deepening and widening the canals, and giving the water a free flow down to the northern lakes. As regards the lowering of the water level wherever it is now continuously too high, and the introduction of weekly rotations, I am at one with him; but I cannot see how giving the waters a free flow down to the northern lakes can assist in working a cure. What I recommend is an easy, cheap and plentiful water supply, alternating with periods of low levels in the canals, and at all times efficient drainage.

But I must remember that the Introduction is the ante-room to which I am confined, and that I have no right in the audience chamber. Therefore anything that I have to say in the way of criticism beyond the foregoing and following remarks, if any more is called for, I must keep for the Irrigation Report of 1899, which has yet to be written, and where I shall not be confined to ante-room limits.

On page 173 of this book "reductions of canal sections to provide flush

irrigation in summer" are referred to as the first mistake of the Department. Though I should like to believe it was only the first, still it is not clear to me what Mr. Willcocks has here in mind. Whatever it may be, the Department has for some time ended and mended it so far as its guiding principles are concerned; for the sections of canals are calculated in all new projects and remodellings to carry the flood supply (25 cubic metres per twenty-four hours per acre commanded) with the water surface only a little above soil. Consequently, as the winter allowance is half and the summer one-third the flood discharge, the mean winter and summer supplies must flow with a water surface well within soil when all the canals have been remodelled. I was under the impression the Department had of late years followed this rule with all new projects. Anyhow, our ideals are what Mr. Willcocks would have them, though we have not yet realised them.

The second mistake he lays to the charge of the Department is the conversion of the tail reaches of many of the canals into drains. Mr. Willcocks has the virtue of being ever ready to admit his share in mistakes, and will not object to my pointing out that on p. 115 of the first edition of this book he shows that he was a consenting party to this mistake, if mistake it was. But I question its being a mistake, and I cannot accept the following statement as accurate, namely, "It (the Department) thus obtained cheap drains badly situated, but lost its flood escapes. Owing to the absence of these tail escapes, many canals have been turned into stagnant pools of water through eight months of the year." I do not understand how the flood escapes are lost: the channels exist, call them drains or flood escapes or what you will; and they are available for carrying away excess water at any time of the year. They may not be, and often are not, large enough to carry off the maximum excess of the year, with a sufficiently low water surface to provide satisfactory drainage at all seasons; but the remedy for that is enlargement by deepening or widening or both, which remedy has been and is being applied to them. As the channels, which Mr. Willcocks calls flood escapes, and which have recently been named drains, still exist, it is not owing to their absence that the tail reaches of the canals have been turned into stagnant pools, wherever such may be the case; but it must be owing to bad regulation and handling of the water in the canal, and also to the ends of the tail reaches being closed by solid dams instead of by tail escapes: for again an ideal state has not yet been reached.

This idea of separating drains and flood escapes is more fully developed in the chapter on Drainage (No. VIII.) The problem is to get rid of excess water during the flood and winter seasons : there is no excess in summer. Mr. Willcocks would solve the problems by providing one channel for the flood excess escaped from canals, and another for the flood and winter drainage. I cannot see why the drainage kitten should not use the same door as the flood escape cat; nor why, if the door is not already large enough for them to pass out together side by side, it should not be made so. The so-called "flood escapes," which have been deepened and enlarged (see p. 235, line 13 *et seq.*) to make them serve as drains, are, as a rule, those which occupy the natural drainage lines of the country, and which have been formed by flood escape water finding its way to the low-lying lakes. I say *as a rule*, as I admit that there have been mistakes, but the mistakes must not be taken as exemplifying the principles that guide us.

The general scheme of drains, which the Irrigation Department is carrying out, is shown on a skeleton map which accompanies the Irrigation Report for 1897.

On this question of the separation of flood escapes and drains, the divergence of our views however may not be permanent. For Mr. Willcocks, on the one hand, is not yet a fossil that has taken on its final shape and is incapable of further change, but a living organism responding freely to external stimuli with the sensitiveness of high development. And I, on the other hand, have not, I hope, yet reached that time when I shall be classified as a geological specimen, instead of as an irrigation officer. Therefore, I look hopefully forward to the Third Edition, to find that our ideas, fed on fuller experience, have grown into agreement on all points on which they now differ.

"Qui color albus erat, nunc est contrarius albo."

Mr. Willcocks has two objections to the weirs being built below the Barrage: one on account of their cost, the other on account of their future effects. He estimates (p. 287) that he could make two stone bars, to reduce the head on the Barrage to 3·50 metres, for L.E. 30,000. This is the estimate of a man out of office, and it reminds me of certain rival estimates that were made by unfriendly and irresponsible critics of the first Director-General of Reservoirs, when his report on various possible reservoir sites was under discussion. Bars of loose stone might be formed

for L.E. 30,000, but not such as would hold water or provide for the passage of boats.

As regards the second objection to "the rising of the water level at the heads of the canals in June and July," I consider Mr. Willcocks overrates this objection. Before the Assuân reservoir is complete, there will be no raising in June. After it is complete, the raising in June will not exceed the present difference between a good and a bad summer supply, but the date of reaching the supply which will enable us to stop rotations, and satisfy the demands for maize sowings, will be advanced about a month; and August rotations, to which Mr. Willcocks objects, will be done away with. Neither will this necessitate raising the water surface of the main canals in the middle reaches of the Delta more than would be necessary by any arrangement that professed to meet the demand. The vision of "vistas of new areas of saturation and new drains" (p. 287) is then "but a dagger of the mind, a false creation, proceeding from the heat-oppressed brain."

The Author, moreover, expresses an opinion that the Ziftah Barrage should have been built in preference to the weirs below the Cairo Barrage. The alternative was not presented for choice in that simple way. The first question to decide was this: was it advisable to build the weirs, if the Caisse would provide money, for reasons independent of the construction of a reservoir at Assuân or elsewhere? This first question having been decided on its own merits, the second question then became: Given the weirs and an extra water allowance of 300 million cubic metres only of reservoir water for distribution in Lower Egypt, was it worth while spending L.E. 400,000 and extras in constructing the Ziftah Barrage? The question was argued out, and the conclusion arrived at that, though the Ziftah Barrage was acknowledged to be a most desirable work for more reasons than one, its construction would not offer advantages of a sufficiently remunerative character to justify its inclusion in the programme of reservoir works connected with the construction of the Assuân dam, when the nature of the financial arrangements necessary for the carrying out of that programme was taken into consideration. The Ziftah Barrage will probably be undertaken as soon as a satisfactory financial arrangement can be made for paying for it.

Finally, I have a word or two to say on the subject of the chapter that will probably attract most attention at the present time. Chapter XIV. deals with Reservoirs, a subject which, as applied to Egypt, no one has

studied more thoroughly than Mr. Willcocks himself, since it was his sole duty to do so for four years. Still, I make bold to advance an opinion, as to the purposes for which the stored water should be used, which is not in agreement with his. Mr. Willcocks calculates that 2000 million cubic metres of water are necessary "to ensure the irrigation of the existing perennially irrigated tracts"; and he considers that such tracts should be first served. "For whosoever hath, to him shall be given, and he shall have more abundance." But this rule is not going to be followed; for the Author's opinion, right or wrong, is not that which has commended itself to those who are responsible for deciding. It has been considered more just to distribute the benefits of the first reservoir to different parts of Egypt, so that its results may be widely felt; though the lion's share is to be devoted to that purpose which, financially regarded, promises to be most profitable to all concerned.

The reclamation of the low lands on the north of the Delta, which are not only of the worst quality, but are also most unfavourably situated as regards irrigation and drainage, and what is more, where there is no population, cannot easily be brought about except by a gradual process such as has been taking place ever since the Barrage was restored and improvements in the water distribution introduced. Lower Egypt's share of the contents of the first reservoir will give a fresh impetus to a similar pushing forward of the cultivated areas towards the shallow lakes; and the new cultivation and its attendant population will be introduced and become established on the reclaimed areas before a second reservoir makes it possible to push the limit of profitable cultivation still further forward. The programme will be similar to that adopted for Lord Kitchener's advance on Khartoum—slow and sure, with pauses to obtain a firm grasp of what has been gained, and to give time to prepare for the next forward move. The Third Edition of this book may have to tell of these advances, of the construction of the Ziftah Barrage, and of much else that has not yet been thought of.

As regards this Second Edition, I hope, for the sake of the readers, that they may be many. A book such as this is, will ever remain a permanent record of experience useful to irrigation officers in all countries, but most especially to those who have to control the irrigation which is the life of Egypt. It will never more be necessary to send officers out into the country as Sir Colin Scott-Moncrieff had to do, equipped with such absolute ignorance of all the local conditions of the problems with

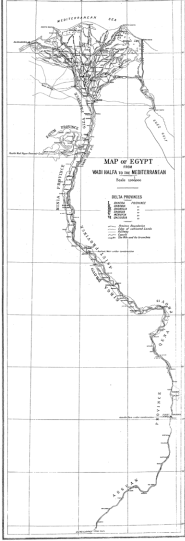
which they were expected to deal, and with no further instructions than that they were to put things right with as little expenditure as possible. This book is a milestone on the road of reform to show what length of it we have left behind us; and a finger-post to point to the road that we should take in front. But it is more than that: its publication is the pushing forward of the head-quarters of our accumulated and systematised knowledge to a point from which we shall not recede, but from which further advances towards the goal of perfection can be made. The Irrigation Officers of the future must always, if the reputation of the Department is to be kept up, approach nearer that goal than their predecessors, for they start from a more advanced post, the permanent possession of which this book secures to us.

R. H. BROWN.

April 12th, 1899.

Errata.

Page 29, line 3 from top, *instead of* "2 metres," *read* "5 metres."
,, 157, line 22 from the bottom, *for* "Mr. Wilson," *read* "Major Brown."
,, 225, line 7 from top, *for* "350,000," *read* "300,000."
,, last line, *for* "light," *read* "lift."
,, 357, line 5 from the bottom, *for* "1887," *read* "1897."



MAP OF EGYPT
FROM
WADI HALFA TO THE MEDITERRANEAN
Scale 1/2000000
DELTA PROVINCES
I BEHERA PROVINCE
II GHARBIA "
III DAQAHLIA "
IV SHARQIA "
V MENUFIA "
VI QALIUBIA "
Province Boundaries
Edge of cultivated Lands
Railway
Canals
The Nile and its branches
MEDITERRANEAN SEA
ALEXANDRIA
SUEZ GULF
GIZA PROVINCE
FAYUM PROVINCE
Possible Wadi Rayan Reservoir Canal
MINIA PROVINCE
ASIUT PROVINCE
Assiout Weir under construction
GIRGA PROV
QENA PROV
Assuan Dam under construction
FIRST CATARACT
ASSUAN PROVINCE

PLATE I

EGYPTIAN IRRIGATION.

CHAPTER I.

EGYPT.

Geology of N.W. Africa—Egypt between the First and Second Cataracts—Deserts between Halfa and Assuân—Gebel Silsila—Gebelain—Nile valley, Assuân to Cairo—The Fayûm and Lake Kurûn—Meteorology—Analysis of the soil and water—Evaporation and absorption—Trees—Animals—Railways—Roads—Navigation—Population—Yield of lands, Upper and Lower Egypt—Principal crops and their value—Cotton and sugar production, 1878–1898—Rents—Classes of proprietors and density of population—Sizes of holdings—Areas of different classes of land according to system of irrigation—Values of flood and perennially irrigated lands compared—Imports and exports—Revenue and expenditure—Debt—Irrigation budget.

THE Egypt treated of in this book extends from 22° to 31° 30′ N. lat., along the valley of the Nile. Wady Halfa is the southern limit, and the Mediterranean Sea the northern. The 30th parallel of latitude, which passes through Cairo, divides the country into Upper and Lower Egypt, the former lying to the south, and the latter to the north. Since the important question of reservoirs renders a general knowledge of the rock formations of the Nile valley a matter of considerable importance, I shall begin by giving a general description of the geology of the Nile valley and the surrounding deserts. This description has been written for me by Captain Lyons, R.E., Director-General of Surveys. The geological description will be followed by a sketch of the Nile valley from Wady Halfa to the sea, looked at solely from the point of view of the hydraulic engineer.

"Situated in the largest rainless area of the world, the topography of Egypt is more directly determined by its geology than in countries where a regular rainfall is constantly eroding the valleys, and annually removes a large amount of solid material from the land.

Egypt is occupied mainly by a great thickness of sedimentary deposits of Cretaceous and Tertiary age, which have been laid down upon the uneven and eroded surface of a great mass of crystalline rocks, which come to the surface along the eastern boundary of the country, and cover considerable areas in the eastern desert of Egypt and Nubia. Westwards of this extend the rocky desert plateaux formed by the Nubian sandstone (Cretaceous) south of latitude 25°, and by the Tertiary limestones to the north of this as far as Cairo, latitude 30°.

The Nile valley itself and the cultivable soil which has been deposited in it during

many thousand years, occupies a generally north and south direction in this sedimentary plateau, and is due to the great earth movements which took place over what is now North-eastern Africa and the adjoining part of Asia in Miocene times.

There must then have been extensive fracturing of the earth crust, and the long depression now occupied by the central African lakes, the low area south of Abyssinia, the Red Sea, the gulfs of Suez and Aqaba and the Jordan valley, was the result.

Throughout Egypt there is clear evidence of considerable movement, and the Nile valley itself has been determined by a line of fracture which is traceable from the sea nearly to the First Cataract.

Into this valley in late Miocene or early Pliocene times the sea penetrated at least as far as Esna, and laid down thick deposits of sand and gravel on the floor of the valley and up to the foot of the cliffs bounding it, while the tributary streams, fed by a rainfall much heavier than that of to-day, brought down masses of detritus from the limestone plateaux and piled them up along the margins of the valley. A subsequent rise of the area converted this "fiord" into a river valley, and the deposition of the Nile mud and the formation of cultivable land began.

The crystalline rocks commence in latitude 28° N., and form the southern portion of the Sinai Peninsula and the range of hills which border the Gulf of Suez and the Red Sea, and extend as far south as the northern boundary of Abyssinia. In width they gradually increase, reaching two-thirds of the way to the Nile east of Kena, while at Assuân, Kalabsha, Wadi Halfa and at numerous points further south they occur in the valley of the Nile, forming cataracts and gorges, though often still hidden over large areas east of the Nile by the Nubian sandstone.

In the western desert one solitary hill (Jebel Abu Bayan, 15 kilometres south of the Kharga Oasis) occurs, which is a peak rising through the superincumbent sedimentary strata.

In the northern part of this area, east and north-east of Kena, they consist of the following general divisions.

At the base is a gneiss, overlain by mica, talc and chlorite schists, above which is a very thick volcanic series, and into this are intruded a grey hornblendic granite and also later a red granite. They often form high mountain peaks, among which Jebel Gharib, Jebel Abu Harba, and Jebel el Shaib, all 200 metres or more in height, are the principal ones in the northern area, while in Sinai there are some which rise to 2500 metres.

The best known of these rocks is the red hornblendic granite of Assuân (syenites of Pliny) which was used so largely by the ancient Egyptians for statues and parts of their temple buildings. Besides this there occurs in the volcanic series at many points, and especially at Jebel Dukhan, the celebrated imperial porphyry which was so much in request for the buildings, &c., of the Roman emperors.

Many other kinds of these hard rocks were worked for ornamental purposes, and the minerals they contained, iron, copper and, in a few places, gold, were extracted from them by crude methods through the agency of gangs of prisoners and criminals.

In Egypt and Lower Nubia, Wadi Halfa, Kalabsha and Assuân are the three points where the old surface of these rocks lies nearest to the surface, and consequently where the river has formed cataracts in making its way through them after cutting down through the overlying sandstone.

More recent volcanic rocks occur at many points in Egypt, though they cover no large area: and an outcrop of basalt (olivine-dolerite) is worked near Abu Zabel on the east side of the Delta for road metal, &c., furnishing a dense black fine-grained rock of great durability.

On the eroded surface of the crystalline rocks has been laid down over a very large area the *Nubian sandstone*. This is a yellowish sandstone which at its base usually becomes a quartz conglomerate. It covers almost the whole of Nubia, and in Egypt extends from Assuân nearly as far as Esna, where it passes under the clays and limestones of Cretaceous age. Equal in texture and easy to work, it has always been in request as a building stone, and all the ancient temples in the southern part of Egypt and Nubia have been constructed of it. Gertassa, 40 kilometres south, and Silsila, 70 kilometres north of the First Cataract are the principal places where it was quarried.

Above these lie a large series of green and grey clays with thick banks of soft white limestone, and here and there thin beds largely composed of fish remains and yielding a fair percentage of phosphoric acid. These beds are of no special importance, and in the Nile valley are succeeded with hardly any apparent break by the lower Eocene strata. The unconformity between them is, however, very clearly marked at many points in the deserts east and west of the Nile.

From this point in the geological sequence, we have an immense thickness of soft white limestone which forms the cliffs of the Nile valley from Luxor to Cairo, and furnishes almost the whole of the building stone in Egypt. Here and there harder and more siliceous beds occur locally (as at Issawia near Sohag), but on the whole it is a soft stone and one which deteriorates when exposed to the weather, and especially if it contains much salt, as it often does.

North of Cairo there is no building stone of any value except the siliceous sandstone of Jebel Ahmar near Cairo, and the basalt of Abu Zabel already mentioned. The Jebel Ahmar sandstone belongs to a shallow water deposit which has been in many cases cemented into a hard refractory rock by silica, an action intimately connected with the numerous local outbursts of basalt which occur plentifully in this part of the desert.

In ancient days this stone was very largely used for the temples of the Delta, and to-day Jebel Ahmar itself is little more than a mound of quarry rubbish.

Miocene limestones have been locally worked at Jebel Geneffa on the Suez Canal, but the beds have no great importance in the Nile valley.

All the above succession of strata have been affected by the great earth movements of the Miocene period, which have been already referred to as initiating the Red Sea, Gulfs of Suez and Aqaba and Jordan valley depression, and also the Nile valley of Egypt, which was filled by an arm of the sea as far apparently as Esna, while, to the north of the western desert, in the neighbourhood of the Wadi Natrun, were shore lagunes. As a result of this thick deposits of sand and gravel were laid down, which to-day underlie the later Nile mud deposits and which furnish a good and easily obtainable water supply.

After this, climatic conditions analogous to those of to-day seem to have soon set in, and river deposits of dark sandy mud were laid down which were at levels considerably above the deposits of to-day.

Nile mud with shells similar to those now existing occurs in Nubia at 30 metres, and in Egypt at lesser heights above the present Nile flood level.

To-day the Nile is depositing in its bed at the rate of about 0·12 metre per century.

The thickness of the layer of the Nile mud in the valley is given for several places where borings have recently been made:—

	metres		
Benha	17		In the Delta.
Mehallet Roh	18		
Qaliub	12·5		
Tanta	—		
Zagazig	33	(Prof. Judd, F.R.S.)	In the Nile valley."
Beni Suef	11		
Sohag	17		
Tahta	—		

It has been already stated that the rocks traversed by the Nile at the cataracts are crystalline. In the Second Cataract there is a very fine outcrop of granite at the Semne rapid; but from there on to Halfa the latter rock is scarce, and this part of the cataract is consequently ill suited for dams of any magnitude. The crystalline rocks have a general fall westwards, and can be seen disappearing under the Nubian sandstone near the water's edge at the rock of Abusîr. Of the 345 kilometres which lie between the Second and First Cataracts there are 305 kilometres of Nubian sandstone and 40 kilometres of crystalline rocks. The latter are met with at Abkhôr, Kalabsha, and from Debod to Shellal. The only point where sound granite is met with between the two cataracts is Kalabsha, where there is an island of this rock south of the narrow pass. The depth of water here is excessive, and in the pass itself, which is 155 metres wide, the depth of water in low Nile is 33 metres.

The Nubian sandstone, which is met with nearly everywhere, is totally unsuited for supporting dams of any magnitude. Not only is the stone itself weak, but it has interposed between the strata of sandstone, layers of yellow and violet coloured marls. Of the unreliability of these marls a very good example is to hand at the rock-cut temple of Abu Simbel, 70 kilometres north of Wady Halfa. One of these belts of earth passes some distance above the cornice at the top, and another along the knees of the colossi. The knees are very considerably degraded, while the upper belt of earth, in decaying, had left the superposed layer of sandstone projecting forward in an exceedingly dangerous manner. One big fragment from this superposed stratum had already in the past fallen on the head of the second colossus, counting from the left, and had completely destroyed it, while the existence of the first colossus on the left was threatened by the fellow of the rock which fell before. In 1890, M. Roux and I had crept along the face of the hill under the overhanging rock, but the following year found our passage barred by a decided subsidence. This matter was brought to the notice of Wodehouse Pasha, the commandant of the frontier, who took the matter up warmly, and had the whole hill thoroughly

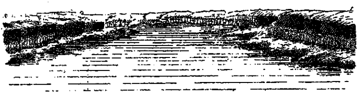
examined and all the loose and dangerous rocks cemented by a party of English soldiers under Captain Johnson, R.E.

There is a complete absence of fossils in the Nubian sandstone. Very occasionally strata are met with which contain traces of salt or lime, but both these substances are very rare indeed. The violet coloured earthy strata crumble away when exposed in a vertical section, but where a stratum comes to the surface the uppermost layers become covered with black blisters, which increase in size and form eventually round hollow



TYPICAL DECAYING SANDSTONE.

black balls which cover the face of the desert. These are the infernal bombs so graphically described by Sir Samuel Baker in his account of the desert journey from Korosko to Abu Hamed at the beginning of the 'Nile Tributaries of Abyssinia.' There is also a stratum of deep red sandstone, which on coming to the surface hardens into vitrified looking masses. Wherever these bombs and balls cover the hills there is no flying sand and the deserts are hard and clean, both banks of the Nile valley are



TYPICAL SANDSTONE NOT IN A STATE OF DECAY.

cultivated and there is no fear of sand drifts. When these substances do not exist on the surface of the desert the sandstone hills are in full decay, and the flying sand fills up the valleys, forms dunes, and we have the ideal wilderness. The western bank of the Nile is buried under sand under the action of the prevailing north-west wind, and cultivation is confined to the right bank.

Descending the Nile from the Second Cataract, we find it flowing between sandy and degraded hills past Wady Halfa. The left bank is

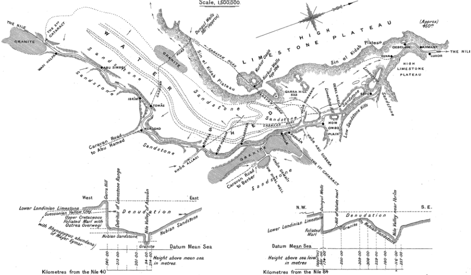
nearly everywhere low and mean and covered with sand drift. Here and there are evidences of ancient cultivation, but as the struggles of the inhabitants against the sand drifts have been intermittent through centuries, while the action of nature has been unceasing, the cultivated land has dwindled to a minimum.

From Abu Simbel northwards, the valley is bounded on the left by a high limestone plateau, known as the "Sin el Kidab,"* which is at first 90 kilometres away from the Nile, but gradually approaches until at Assuân it is 40 kilometres away, and from Gebelain northwards comes close to the river. Between Esna and Gebelain a similar plateau appears on the right bank of the Nile, like a table mountain, rising out of the midst of degraded hills. I had two cross sections of the Nile valley levelled, one at Ibrîm, north of Abu Simbel, and the other at Assuân. They are given on Plate II. The reduced level of the Nile in flood is at Ibrîm 116 metres, and at Assuân 94 metres, while the general level of the plateau is 450 metres, and its highest point, the Garra Hill opposite Assuân, is 540 metres above the sea level. The dip of the strata everywhere is north-west. On this plateau are the Kurkur and Dunkul wells. At the top of the Garra Hill are some 90 metres of lower Londinian limestone, then a 5-metre belt of Suessonian yellow clay literally living with Echinoids, and then about 230 metres of foliated marl of the Cretaceous formation, with a thick belt of *Ostrea Overwegi* in the middle. Below these stretches away the sandstone plain. Near Garra the sandstone is calcareous, but as we approach the Nile we have the ordinary siliceous Nubian sandstone. The Kurkur wells are at the east end of the so-called Kurkur Oasis, a basin on the top of the plateau, where there are a few acacias and dôm palms. There is always an abundance of good water at Kurkur. The Dunkul well is a cup on the top of the range. There is very little water here and one cluster of dôm palms, though about 5 kilometres to the north there is a valley with numerous Sallim acacias. The two sections of the Nile valley at Ibrîm and Assuân, which accompany the plan on Plate II., show how heavy the denudation has been. At Assuân it must have been fully 60 kilometres × 300 metres, and at Ibrîm 100 kilometres × 150 metres. The excessive denudation in this reach is due to the fact that the thick belt of foliated marl which intervenes between the limestone and sandstone strata has generally no consistency whatever, and in the presence of water must have melted away like sugar. Where, however, this foliated marl has consistency, as it has on the right bank of the river from Basilia to Gebelain, it contains deposits of nitrates, which render it a valuable manure.

* "Sin el Kidab" means "the liar's tooth," and is used by the Arabs to define this plateau, as its great height makes it appear closer than it really is, and if you think you will reach it in one day, it will take you a day and a half.

PLAN OF THE NILE VALLEY FROM WADI HALFA TO LUXOR.

Scale, 1,500,000.



CROSS SECTION OF THE NILE VALLEY NEAR ASSUÂN

CROSS SECTION OF THE NILE VALLEY NEAR IBRÎM

Longitudinal Scale – Same as Plan.
Vertical Scale: 15,000.

A cursory examination of the two cross sections will show the impossibility of storing Nile water in the deserts of Nubia north of Wady Halfa, outside of the trough of the Nile.

The arrow heads on the plan show the direction of the rain-water to-day. It rains once in two or three years. The watershed is close to the Nile on its left bank, but on the right bank the whole of the desert drains into the Nile through seven main Khôrs and numerous minor ones.

At the First Cataract there is an extensive outcrop of granite and quartz diorite. These rocks are very hard and compact, and well suited for the foundations of important works. It is just where the rock is hardest and most compact that the alignment of the Assuân reservoir dam, under construction, has been fixed.

Between Assuân and a point a few kilometres to the south of Esna (where the Nile may be said to enter the limestone hills which skirt it as far as Cairo) the river is between sandstone hills except at two places, the plain of Kom Ombo and the plain of Edfu. These two plains were ancient deltas of rivers coming down from the high ranges which skirt the Red Sea. There are solitary limestone hills standing in the two plains surrounded by sandstone. The sands and clays of the Edfu and Kom Ombo deltas, of an age anterior to the Nile, are covered with pebbles of porphyry and granite brought down from the Red Sea range. These stones have no affinity to those met with at Assuân, Kalabsha or Halfa.

About 35 kilometres to the north of Assuân we enter the Kom Ombo plain, with Nile deposit 25 metres above the maximum flood level of to-day. About 8 kilometres downstream of the Kom Ombo temple, on the left bank of the Nile, is a very good section showing the relative positions and depths of the ancient sandy clay and sand deposits overlaid by the more recent Nile mud. At Raghama (kilometre 60) we meet with limestone for the first time in coming down the valley of the Nile. Immediately north of it is the Silsila sandstone. There is apparently no other limestone in the valley of the Nile south of Silsila, right up to Lake Victoria, though Sir Samuel Baker has stated that there is kankar south of Khartoum.

It has been imagined that the Gebel Silsila pass was an ancient cataract of the Nile. Though the present channel is narrow, yet it is only a branch of the river; the real channel, 1500 metres wide and over 15 metres deep, is on the right of the hill in which the quarries are, and is at present buried under mud and silt. Silsila itself can never have been a cataract, for the Nile deposits and ætheria shells are met with north and south of the pass at exactly the same level, and no change is experienced until we reach Gebelain, where there is a decided drop in the level of the ancient deposits. The upturned and undermined hills which strew the Nile valley at Gebelain

encourage one in the belief that here was the site of a great cataract in the remote past.

From Assuân northwards the sandstone is generally inferior to that south of the first cataract, while the belts of yellow clay increase in thickness and number, until finally the sandstone gives place to the foliated marl which underlies the limestone. The low hill to the right of the Gebel Silsila pass is, however, an exception to this general rule and contains very good stone. Here, on the right bank of the river, are the extensive red sandstone quarries of the ancient Egyptians.

That part of the "Sin el Kidab" plateau which was cut through at Gebelain was only a promontory, and at Luxor the Nile again emerges into the low denuded plains on its right hand, having the plateau as a wall on its left. To the north of Kena the plateau is entered for the second time, and from here to Cairo the Nile keeps between limestone hills on either side. At Kena the lower Londinian formation dips below the level of the Nile deposit, and the upper Londinian formation monopolises the whole section of the limestone as far as a point midway between Assiout and Minia. Here the lower Parisian strata appear on the tops of the plateaux, and the upper Londinian strata finally disappear a little to the north of Minia. The lower Parisian formation is now generally met with as far as Cairo. All these limestones, like the sandstones, are unfit for supporting reservoir dams of any magnitude. Serious failures of dams built on these very formations in Algeria have proved their total unfitness for such works. In Appendix I. will be found a description of the principal Egyptian stones and their power of resistance to crushing, as tested by Professor Hudson Beare, of University College, London. In the same appendix the power of Egyptian mortars to resist tensile stresses is also recorded.

It has been already said that the left or western bank of the Nile in the Nubian sandstone is, with slight exceptions, inundated with flying sand. In the limestone, however, these invasions of flying sand are not so general. Flying sand of a not very serious character is met with on the left bank of the Nile in the vicinity of Armant; to the north of Delga; and along the left bank of Geeza province. Serious invasions of sand are going on in Minia province north of Balansura for a distance of some 60 kilometres; in the Garak depression of the Fayûm; and in the first 30 kilometres of the Rosetta branch of the Nile. In the Minia province, on the fore-mentioned length of 60 kilometres, an area of some 20,000 acres of cultivated land has been completely buried under sand which is surely but deliberately travelling eastwards, and has more or less injured an equal area of land lying to the immediate right of the destroyed tract. Strenuous efforts should be made by the Government to stop any further progress of the sand by means of plantations of tamarisks and grasses.

If the mean width of the Nile valley as it traverses the different rock formations may be taken as an indication of the power of the different rocks to withstand the action of the water, it may not be without interest to state that in granite the width is 160 metres, in the crystalline rocks 500 metres, in sandstone 2000 metres, in the Lower Londinian limestone 8000 metres, in the Upper Londinian 13,000 metres, and in the Parisian limestone 18,000 metres. To the north of Lahoun, where the Bahr Yusuf enters the Fayûm, the Nile valley in Parisian limestone contracts to a width of 7000 metres, doubtless because great part of the water of the ancient river found its way westwards through the Fayûm and Wady Rayan depressions. The enormous masses of salty and bitter marls, loams and clays which have been deposited at the Lahoun bifurcation and to its south-west, reminded M. Boulé, the French member of the Reservoir Commission, of the corresponding marls in the Paris basin which make foundation works so dangerous there. These same marls and clays underlie the Nile deposit of the Fayûm over the greater part of its area. They are very salted, and difficult to reclaim for agricultural purposes. The Fayûm province is a deep depression in the desert scooped out of the Parisian limestone, and as just remarked, overlain in great part by thick belts of salted loams and marls. On these salted loams has been deposited Nile mud to a greater or less depth. To the north of the province is the Kurûn Lake, with its water surface about 40 metres below sea level. It is all that remains of the ancient Lake Mœris of which so much has been written. Appendix II. contains an interesting paper by Dr. Schweinfurth on the salt in the Wady Rayan. He attributes the fact that the waters of Lake Kurûn are only slightly brackish to the fact that there must be very considerable subterranean drainage. These drainage waters, he argues, descend to great depths, become intensely hot, and are then discharged below the Mediterranean Sea. I quote some of his arguments :—

"I conclude by calling attention to the extraordinary phenomenon of the water of Lake Qurun in the Fayum being nearly sweet, in spite of the fact that it is the residuum of the ancient Lake Mœris. This question is intimately connected with that of the proposed Wady Rayan reservoir. Very probably the creation of the depression of the Fayum and the subsidence of the strata composing its bed were due to the same geological action which produced the Wady Rayan. This reflection makes it probable that this latter reservoir, when it is full, will disclose the same clefts and fissures in its bottom, which I shall try and prove, exist in the bed of the Qurun Lake.

These subterranean passages will cause the loss of a great part of the water stored in the reservoir, and will give birth to distant springs, and probably even to the formation of new oases in the Libyan desert. The effect on the reservoir will be the following: the quantity of salt in the reservoir will be diminished, but the work of the filling the reservoir will be more difficult and longer in operation.

The Qurun Lake has to-day a surface of about 250 millions of square metres, and probably a cubic content of 1500 millions of cubic metres.

If we suppose that the lake has existed at this same level since the Roman period (A.D. 200), the lake would have received salt from the Nile since that period.

		In millions of grammes
1. Salt in the entire mass of the water, 1500 × 40	. =	60,000
2. Salt contained in the strata of water evaporated annually during 17 centuries, 2 × 250 × 40 × 1700	=	34,000,000
Total	.	34,060,000

The salt in this case would amount to 34,060 millions of kilogrammes, i.e. 2·27 per cent.

As, however, at the time in question, the lake had very probably its water level at + 0, its volume has decreased by 43 metres in perpendicular height during the 17 centuries. We must therefore find the quantity of salt in the water which was in excess of the present volume of the lake, and the annual loss by evaporation off the excess of the surface of the lake over the area of to-day. This latter excess equalled, in all probability, the present area of the lake.

At R.L. 0 the area of the lake was approximately 500 millions of square metres, and its excess volume was from 13 to 14 times the actual volume of to-day. I estimate this excess volume at 20,000 millions of cubic metres and the salt at 800,000 millions of grammes. The diminution of the surface of the lake was slightly under 250,000 square metres per annum. The salt contained in the strata of water evaporated outside of the actual area of the lake to-day amounted in 17 centuries to 17 billions of grammes. This total quantity of 17,800,000 millions of grammes of salt in 1500 millions of cubic metres of water give a percentage of 1·186.

If we add 1·186 to 2·27 found before, we have 3·45 per cent. of salt in the lake to-day if it had existed only 1700 years; and at the beginning of that time had been at level of the Mediterranean.

So far I have not considered the supply of salt from other sources such as:—

1. The infiltration water brought into the lake by the canal and drains from the cultivated land of the Fayum.

2. The greater quantity of salt in the Bahr Yusif on entering the Fayum, than in the Nile itself.

On the other hand, I have exaggerated in giving for the whole year the percentage of salt which is in the Nile only during flood.

Any way, one will readily see to what degree of concentration the salt ought to increase in a lake whose volume has been so considerably reduced through incalculable centuries. . . . . This would represent a percentage of salt of 8·53.

But who knows since when the great lake existed, and how many centuries elapsed before the controlling of its water was begun? What has become of the salt which would have mounted to figures far higher than mine? Where again are the salts contained in the basin before the Nile water entered, and the salt of infiltration from drainage and irrigation? The salt in the lake to-day bears no relation to the quantities I have enumerated.

To-day the waters of the Qurun Lake are but slightly brackish. They are even

potable, and inhabited by fresh-water fish from the Nile. It has been definitely proved that Lake Mœris never had a natural outlet towards the interior of the country, and that it never even was in connection with the Wady Rayan, which it nearly touched. (See Major Brown's work on the Fayum, pp. 43 and 48.) The Fayum basin is closed on all sides by bluffs and hills of considerable height. We have seen that, in spite of their concentration through immemorial ages, the salt in the waters of the lake has not increased. This renewal of fresh water can only be accounted for by subterranean drainage. Where have the waters gone to?

(Lake Tchad in the central Soudan is an example of subterranean drainage on a larger scale. The waters are perfectly sweet in spite of the absence of any apparent outlet. The lake is drained by active infiltrations towards the north-east in low depressions which are known as the Bahr El Gazal.)

The Natron Lakes are probably due to direct infiltrations from the Nile, since Sickenberger in 1892 observed that all the springs which gave birth to the lakes were situated on the eastern side of the valley. The difference of level, also, prevents the establishment of any similarity between the systems, as well as the fact that the springs of the Natron Lakes are not thermal.

Oases and depressions provided with springs are to be found to the north-west of the Fayum as far as Siwah; and this latter oasis may perhaps obtain some of its water from the Qurun Lake in spite of the difference of levels. There are many phenomena connected with thermal springs which as yet await solution. We are still in ignorance of the destination of the currents of those thermal springs which traverse the bottom of the depression of the Great Oasis and the oasis of Dakhel, at great depths. These springs are abundant and flow evidently towards the north. It is probable that all these subterranean streams, which are fed by the Nile, flow towards the Marmarica coast between Alexandria and Derna. There, owing to the tensile force inherent in all water at a high temperature, they are discharged at great depths below the level of the Mediterranean Sea."

I have obtained from Captain Lyons, R.E., the following information about the meteorology of the Nile valley:—

"Except the northern margin of the Delta, the climate of Egypt is that of the great desert area of North-eastern Africa, the rainfall being extremely small and occurring mostly as occasional thunderstorms.

Along the Mediterranean coasts there is a considerable rainfall in the winter months, but this only extends for a short distance southwards, and at Cairo ten or twelve rainy days a year is probably the average. South of this the amount decreases rapidly, and from Cairo to Luxor and in the neighbouring deserts, showers on one or two days and an occasional thunderstorm represent probably all that falls in an average year. South of this nothing but an occasional storm of rain ever falls, though this falling on the rock desert, bare of all vegetation, drains rapidly into the nearest wadi, and in a few minutes forms a torrent often as much as 2 metres deep, sweeping tons of stone and gravel with it, and often drowning men and animals who are caught by it.

South of Cairo no regular rainfall observations have been made, but the following table gives the average annual rainfall for six places in Lower Egypt:—

Place	Rainfall in millim.* per ann.
Alexandria	210
Port Said	89
Ismailia	54
Suez	28
Cairo	27

In the following table † are given the average temperatures (Centigrade) for five places in Lower Egypt and two in Nubia for the months of January and July, as well as the mean of the year.

Place	Jan.	July	Annual Mean	Extreme Min.	Extreme Max.
Alexandria	14·4	26·2	20·6	7·3	37·4
Port Said	13·5	27·8	20·5	—	—
Ismailia	12·6	28·1	20·5	—	—
Suez	12·1	29·2	21·5	—	—
Cairo	11·9	29·1	21·3	2·5	42·9
Assuân	16·7	34·9	26·7	5·5	48·1
Wadi Halfa	16·3	34·1	26·3	5·1	47·1

The prevalent winds in Egypt and Nubia are N., N.N.W. and N.W., which blow the greater part of the year.

In winter, S. and W. winds often prevail for a short time, and in the spring and early summer the N.N.E.—N.E. wind is frequent. On the whole, however, the N.N.W. wind may be said to be by far the most important wind, and its effect is seen in the lines of dunes in the western desert, which are sometimes over 200 kilometres in length, lying in the direction of this prevalent wind."

No substantial additional information about the analysis of the soil and the Nile has been obtained beyond what was known when I wrote my first edition, and I consequently reproduce what I then wrote. I may state that Dr. Mackenzie, of the Agricultural School, has taken a series of very careful observations, but as the specimens of Nile water he analysed were unfortunately taken from a point just downstream of where the Nile was eating away a sandy island, his results are, I am afraid, no true gauge of the matters held in suspension in ordinary Nile water.

According to the French *savants* of the beginning of this century, the analysis is—

Water	11	in 100 parts.
Carbon	9	
Oxide	6	
Silica	4	
Carbonate of magnesia	4	
" lime	18	
Alumina	48	Note the excess of alumina and lime.

* Hann's 'Klimatologie,' ii. p. 143.

† Op. cit., iii. p. 73.

After an analysis made by Messrs. Payer, Champion and Gastinel at Paris, in 1872, the result is—

Silica	·45	in 100 parts.
Argil	·53	
Magnesia	·2 to 1·6	
Lime	1·3 to 4·9	
Azote	·03 to ·1	
Phosphoric acid	·03 to ·32	

The very careful analysis made by Dr. Letheby and Professor Wanklyn in 1874–75, of Nile water, given in Mr. B. Baker's paper,* gives the sedimentary deposit of Nile water in the flood of 1874 as—

Organic matters	15·02	in 100 parts.
Phosphoric acid	1·78	
Lime	2·06	
Magnesia	1·12	
Potash	1·82	
Soda	·91	
Alumina and oxide of iron	20·92	
Silica	55·09	
Carbonic acid and loss	1·28	

It is unfortunate that the flood of 1874 was an exceptional one altogether; indeed a flood similar to 1887 in every way, but totally different from a mean flood like 1886, or a low flood like 1884. It may be gathered from this that the water was light in colour and clear in consistency, as compared with ordinary years like 1886, and very clear compared with dark muddy low floods like that of 1884. It may also be gathered that the quantity of sand brought down, owing to the strong force of the current and the ability of the clear water to take up sand from the river's bed, was also excessive. Dr. Letheby's analysis is therefore more like that of the sandy Nile berms, formed in years similar to 1874 and 1887, than of the ordinary clay soil of Egypt, analysed by the French *savants*. The soil of Upper Egypt, and Lower Egypt down to a contour of 7 metres above the Mediterranean, is practically free from salt in excess, except where very high lands are being perpetually irrigated by lift, and never washed by a flood. Below a contour of 7 metres, however, bad drainage is always accompanied by salt efflorescence. Below a 3-metre contour, salt is everywhere in excess, and the land needs very careful drainage and frequent washings. Below a 1·50-metre contour, the land has practically still to be reclaimed. When it is considered that the bottom deposits of Nile alluvium have always been in sea water, and that up to 1·50 metres above sea level they have frequently been washed by the sea, it is not to be wondered at that capillary attraction brings salt easily to the surface in the northern part of Lower Egypt. In Lower

* 'Minutes of Proceedings,' Inst. C.E., vol. lx. p. 367. Now Sir Benjamin Baker, K.C.M.G.

Egypt, above a 6-metre contour, wells are freely used for irrigation; the springs are from 3 to 6 metres below the surface. The higher the spring level the sweeter the water; wells in black clay soil give much less, but much sweeter water than those in sand. Below a 6-metre contour, wells are very seldom used, possibly because the water is salt. In the Upper Egypt basins, wells are dug everywhere for summer irrigation; the water is from 3 to 5 metres below the surface, and sweet.

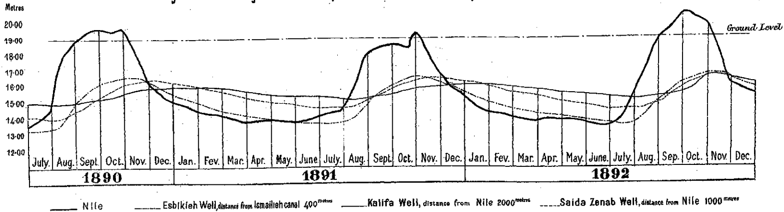
The rise and fall of spring levels depends on the soil, which varies considerably. Where the ordinary compact clay soil of Egypt is met with, the rise of the Nile has not much effect at the surface of the country. The Nile may be 3 metres above the level of the country, and the fields will be as dry as in the height of summer. Where, however, the soil is sandy, a few days after the Nile has risen about a metre above the level of the country, every field becomes a stagnant pool of black water, which reaches up to half a kilometre from the river, and in some places even a kilometre. Immediately the Nile falls, however, the spring level falls with it. The water in the wells rises and falls with the river, much in some places, little in others. At a well near Cairo, in apparently sandy soil, Sir J. Fowler found the water rise 3·7 metres above its minimum, while the Nile rose 6·1 metres. The wells in the Delta depend for their springs as much on the main canals as on the Nile itself. The spring level in the southern half of the Delta proper has been permanently raised by the extra height to which the water has been held up in summer at the Barrages since 1884. Fellaheen have frequently informed me, that owing to this rise they have been enabled to put in extra wells, both on account of the extra water, and of the easiness of lifting it two metres or so less than before. (This rise of spring level constitutes a very great danger to Lower Egypt.) In low hollows and tanks in the clay soil there is little water during the floods, as evaporation is more active than infiltration in such soil. During winter, however, the infiltrations continue, the evaporation decreases, and the tanks soon fill. In clay soil, therefore, infiltration may be taken as less than the evaporation in summer.

In Upper Egypt the evaporation may be taken as high as seven-and-a-half millimetres per day in summer. This figure is obtained from the following calculation.

Lake Kurûn, in the Fayûm, covers an area of 307,000,000 square metres, and lies 40 metres below mean sea; it fell exactly 40 centimetres during May and June 1887.

		cubic metres evaporated
Of the water in the lake (307,000,000 × ·40) .	=	122,800,000
Of the water received from canals 30 × 330,000 .	=	9,900,000
and 30 × 210,000 .	=	6,300,000
Total . .		139,000,000

Diagram Showing the Effects upon the Subsoil Water by the Rise & Fall of Nile at Cairo.



This diagram has been taken from Sir John Roger's report on "the Sanitary aspect of the Nile Reservoirs," published by the Egyptian Government in 1894. It shows the fluctuations of the water surface in three wells situated in different parts of Cairo, as compared to the changes in the water surface of the Nile.

evaporated in 60 days, or per day 2,320,000 cubic metres off an area of 307,000,000 square metres, which gives seven-and-a-half millimetres per day. Linant Pasha considered the evaporation in Upper Egypt as nine millimetres per day throughout the year. Monsieur J. Barois, in his treatise 'L'Irrigation en Égypte,' states that the French engineers considered the evaporation off the bitter lakes near Ismailia as three to four millimetres per day between March and August. The Roorkee treatise on Civil Engineering (vol. ii.) says that the summer evaporation of Upper India may be taken as 12½ millimetres per day, while Molesworth says the mean of the year in India is 5 millimetres per day. I had a good opportunity in 1888 of testing the daily summer evaporation in the northern half of the Delta. A tract of 380,000,000 square metres, lying at sea level, received daily for 120 days, from 1st August to the end of November, about 2,000,000 cubic metres per day, and at the end of the 120 days had risen 25 centimetres. Therefore—

		cubic metres
There entered the lake (120 × 2,000,000) . .	=	240,000,000
There remained in the lake (380,000,000 × ·25) .	=	95,000,000
and were evaporated		145,000,000

cubic metres in 120 days, or 1,200,000 cubic metres per day off 380,000,000 square metres, i.e. three millimetres per day. Summing up the above, we may consider about seven millimetres per day as the summer, and five millimetres per day as the annual evaporation of Upper Egypt; and three millimetres per day as the summer, and two millimetres per day as the annual evaporation in Lower Egypt. This would give as 1·825 metres the evaporation for one year in Upper Egypt, and ·72 metre as the evaporation for one year in Lower Egypt. The percolation or infiltration is considerably in excess of the summer evaporation in the sandy tracts, while in the clay tracts it lies somewhere between the summer and winter evaporation of Lower Egypt.

No trees except the date palm and the acacia arabica, or "sant," are common in Egypt. Such trees as are met with are generally sycamores, mulberries, willows, poplars and tamarisks. In the towns the acacia sirisa, or "lebekh," is the principal avenue tree. The fruit trees principally cultivated are the vine, the fig, oranges, lemons, bananas and apricots.

Outside the principal towns there are no metalled roads. Until quite recently there were no carriage roads in the country, while at the present moment there are 1800 kilometres of unmetalled agricultural roads. Out of 760 kilometres of agricultural railways of 2 feet 6 inches gauge for which concessions have been given, 117 have been opened for traffic in Lower Egypt. The Daira Sania Administration owns 576 kilometres of agricul-

tural railways of 4 feet 8½ inches gauge in Upper Egypt. The following table gives the lengths of the existing railways :—

——	Lower Egypt	Upper Egypt	Nubia	Total
	kil.	kil.	kil.	kil.
4′ 8½″ gauge (Government) .	1242	752	. .	1994
„ (Private) . .	71	. .	. .	71
3′ 6″ gauge (Government) .	. .	209	922	1131
	1313	961	922	3196

I am indebted to Mr. J. Cotterill, of the Egyptian Railways, for the above information.

The number of passengers conveyed by rail in 1897 was 10,742,000, while 2,796,000 tons of merchandise were transported.

Apart from the railways, transport is generally effected by river or canal boats and pack animals. The principal pack animals are camels and donkeys.

At the close of 1897 the registered boats were as follows :—

				tons
Ferry boats	2,074,	with a joint tonnage of		10,500
Barges	46	„	„	4,500
Cargo boats . . .	11,107	„	„	200,000
Fishing boats . . .	1,665	„	„	9,500
Dahabias and house boats .	403	„	„	12,000
Steamers and launches .	113	„	„	6,000
Total . .	15,408	„	„	242,500

Oxen, cows, female buffaloes and camels are used for agricultural purposes, while female buffaloes and cows also supply milk. During the winter months much butter is manufactured. Sheep are very numerous. Horses and mules outside the big towns are animals *de luxe.* Poultry, consisting of fowls, geese and turkeys, is very plentiful, while tame pigeons are reared in millions.

The population of Egypt in 1882 was 6,814,000, and in 1897 was 9,734,000, of which 5,676,000 were in Lower Egypt, and 4,058,000 in Upper Egypt. There were 9,622,000 Egyptians, and 112,000 foreigners in the country. Of the total population of 9,734,000, there were 8,979,000 Moslems, 790,000 Christians, and 25,000 Jews. The males numbered 4,948,000, and the females 4,786,000.

If we consider the cultivated land and the land undergoing reclamation, we may state that the area of Egypt is 5,750,000 acres, of which 4,690,000 acres pay full taxes, while the remaining 1,060,000 acres are in different stages of reclamation and paying taxes more or less in proportion to the

extent to which they have been reclaimed. Of the 5,750,000 acres of cultivable land in Egypt, 2,320,000 lie in Upper Egypt and 3,430,000 in Lower Egypt. Of the 2,320,000 acres in Upper Egypt 2,140,000 acres pay full taxes, and 180,000 acres are partly reclaimed and partly under reclamation. Of the 3,430,000 acres in Lower Egypt, 2,550,000 acres pay full taxes, and the remaining 880,000 acres are partly reclaimed and partly under reclamation. In addition to the 3,430,000 acres, Lower Egypt has another 500,000 acres of salted and marshy land on which no reclamation works have as yet been attempted. These lands are all capable of reclamation. Summing up, we may state that Egypt possesses 4,690,000 acres fully reclaimed and cultivated; 1,060,000 acres under reclamation and partially reclaimed; 500,000 acres on which reclamation has not been attempted; or 6,250,000 acres in all, which are capable of being cultivated, and which were probably cultivated in Roman times before the Arab conquest, when the population of Egypt was 12,000,000 according to the early Arab historians.

In subsequent chapters the different systems of irrigation and agriculture practised in the country will be described. It suffices to state here that the year may be divided into three seasons: the summer, lasting from 1st April to 1st August; the flood, from 1st August to 1st December; and the winter, from 1st December to 1st April. The following tables give the importance of the different seasons, and the names of the principal crops grown in the country, with their gross yields.

For the whole of Egypt the summer crops cover 2,046,500 acres, and yield 15,177,500*l.*

The flood crops cover 1,510,000 acres, and yield 6,870,000*l.*

The winter crops cover 4,260,000 acres, and yield 17,013,000*l.*

The whole area of 5,750,000 acres has a gross yield of 39,060,500*l.*, or 7*l.* per acre.

UPPER EGYPT.

Summer Crops.

	acres			
Sugar cane	75,000 at	£16	=	£1,200,000
Cotton	110,000	10	=	1,100,000
Vegetables, gardens, &c.	15,000	10	=	150,000
Melons	12,500	10	=	127,500
Summer sorghum	160,000	6	=	960,000
	372,500 at	£9·5	=	£3,537,500

Flood Crops.

Dates (trees)	5,200,000 at	£·2	=	£1,040,000
Flood sorghum	510,000 acres	4	=	2,040,000
Rice	20,000	4	=	80,000
	530,000 acres at	£6	=	£3,160,000

Winter Crops.

	acres			
Wheat	600,000 at	£5·0	=	£3,000,000
Beans	500,000	4·25	=	2,145,000
Clover	500,000	4·0	=	2,000,000
Barley	250,000	3·5	=	875,000
Lentils	140,000	3·0	=	420,000
Flax	1,000	8·0	=	8,000
Onions	15,000	10·0	=	150,000
Vetches, &c.	115,000	2·5	=	290,000
	2,121,000 at	£4	=	£8,888,000
Total cultivated area	2,320,000 at	£6·7	=	£15,585,500

The double-cropped area amounts to 703,500 acres, or 30 per cent.

LOWER EGYPT.

Summer Crops.

	acres			
Cotton	1,500,000 at	£7	=	£10,500,000
Sugar cane	4,000	10	=	40,000
Vegetables, gardens, &c.	70,000	10	=	700,000
Sultani rice	100,000	4	=	400,000
	1,674,000 at	£7	=	£11,640,000

Flood Crops.

Dates	2,200,000 trees at	£·2	=	£440,000
Maize	900,000 acres	3·5	=	3,150,000
Flood rice	80,000 acres	1·5	=	120,000
	980,000 acres at	£3·9	=	£3,710,000

Winter Crops.

	acres			
Wheat	600,000 at	£4·5	=	£2,700,000
Barley	330,000	2·0	=	660,000
Clover	955,000	3·5	=	3,395,000
Beans	180,000	3·5	=	630,000
Vegetables, &c.	70,000	10	=	700,000
Flax	4,000	10	=	40,000
Total	2,139,000 at	£3·8	=	£8,125,000
Total area	3,430,000 at	£6·9	=	£23,475,000

The double-cropped area amounts to 1,363,000 acres, or 40 per cent.

The summer crop covers 50 per cent. of the area, the flood crop 30 per cent., and the winter crop 60 per cent. of the area.

The following comparative tables are interesting:—

Year	Cotton Crop in Kantars *	Sugar Cane Crop in tons	Year	Cotton Crop in Kantars *	Sugar Cane Crop in tons
1878	1,700,000	—	1889	3,200,000	31,000
1879	2,700,000	27,000	1890	4,100,000	52,000
1880	2,500,000	8,000	1891	4,500,000	58,000
1881	3,100,000	27,000	1892	5,200,000	54,000
1882	2,500,000	18,000	1893	5,200,000	64,000
1883	2,600,000	30,000	1894	4,600,000	62,000
1884	3,600,000	38,000	1895	5,200,000	83,000
1885	2,900,000	44,000	1896	5,800,000	91,000
1886	3,000,000	42,000	1897	6,500,000	74,000
1887	3,000,000	43,000	1898	5,800,000 (estimated)	—
1888	2,700,000	36,000			

We have hitherto considered the gross yield of the land, and estimated it at 39,000,000*l.* on 5,750,000 acres, or approximately 7*l.* per acre. Of this, Upper Egypt with 2,320,000 acres gives 15,585,000*l.*, and Lower Egypt with 3,430,000 acres gives 23,475,000*l.* If we consider the renting value of the land, we shall find that the renting value of Lower Egypt is 13,700,000*l.*, or 58 per cent. of the gross yield. The renting value of Upper Egypt is 8,300,000*l.*, or 54 per cent. of the gross yield. For the whole of Egypt the renting value is 22,000,000*l.*, or 57 per cent. of the gross yield.

The table on pages 20 and 21 gives the areas of land held by different classes of proprietors, and the population according to the census of 1882 and 1897. The returns of ownership have been collected with the greatest care, and although absolute accuracy cannot be guaranteed, the proportions may be considered as very fairly accurate.

The density of the population in the southern provinces of Upper Egypt, where the deserts contain nitrates and the fellaheen and resident Egyptians possess great part of the land, is in striking contrast to the scarcity of population in the province of Minia, where the same classes possess less than 40 per cent. of the land, and where the deserts contain no nitrates.

The table on page 22 has been taken from a pamphlet on statistical returns published by Sir Elwin Palmer, K.C.B., financial adviser to the Egyptian Government.

The table on page 23 gives the areas of land under different systems of irrigation in Upper and Lower Egypt by provinces. In Upper Egypt there are 1,731,800 acres under flood irrigation, and 587,500 under perennial irrigation. Of the 1,731,800 acres under flood irrigation, 1,435,000 are under basin irrigation, and 296,800 acres are situated on the Nile berms and are more or less perennially irrigated by direct-lift irrigation from the Nile. The 587,500 perennially irrigated acres are dependent

* Kantar = 98·09 lbs.

TABLE GIVING THE PARTICULARS AND APPROXIMATE PERCENTAGE

Provinces	Area in acres	Acres			
		State Domains	Daira Sania (State)	Religious Bodies	Banks, Foreigners, &c.
Upper Egypt:					
Assuân .	73,538	..	4,416	581	48
Kena .	342,936	..	45,255	6,316	12,284
Girga .	324,958	..	..	512	4,154
Assiout .	421,473	6,483	34,871	840	14,875
Minia .	407,485	..	133,700	2,651	16,613
Beni-Suef .	237,374	1,842	13,027	886	1,930
Fayûm .	329,390	39,074	75,686	372	2,539
Geeza .	182,180	..	..	4,464	12,202
Total .	2,319,334	47,399	306,955	16,622	64,645
	Percentage .	2	13	1	3
Lower Egypt:					
Menufia .	351,596	..	91	2,023	14,492
Garbia .	1,077,047	186,981	15,084	34,400	208,449
Kaliubia .	191,843	..	25	347	13,559
Sharkia .	568,484	..	3,967	2,560	29,618
Dakhalia .	514,462	3,077	11,507	1,518	56,149
Behera .	734,395	2,852	907	15,790	197,270
Total .	3,437,827	192,910	31,581	56,638	519,537
	Percentage .	5	1	2	15
Totals:					
Upper Egypt	2,319,334	47,399	306,955	16,622	64,645
Lower Egypt	3,437,827	192,910	31,581	56,638	519,537
Grand total .	5,757,161	240,309	338,536	73,260	584,182
	Percentage .	4	6	1	10

OF THE LAND POSSESSED BY VARIOUS CLASSES OF LANDOWNERS.

owned by		Census, 1882		Census, 1897	
Non-resident Egyptians	Resident Egyptians and Fellaheen	Population	Population per 100 acres	Population	Population per 100 acres
3,493	65,000	158,265	214	240,382	320
27,334	251,747	486,827	150	711,457	206
35,775	284,517	521,413	160	688,011	211
40,233	324,171	563,049	135	782,720	185
95,852	158,669	315,803	77	548,632	134
102,652	117,037	219,573	92	314,454	131
51,210	160,509	228,709	71	371,006	112
38,259	127,255	283,833	155	401,634	225
394,808	1,488,905	2,777,472	119	4,058,296	175
17	64				
44,226	290,764	646,013	181	864,206	245
261,055	371,078	936,276	87	1,297,656	120
71,158	106,754	271,391	141	371,465	193
176,787	355,552	471,139	83	749,130	131
212,746	229,465	588,644	114	736,708	140
216,586	300,990	401,730	55	631,225	85
982,558	1,654,603	3,315,193	97	4,650,390	135
29	48				
394,808	1,488,905	2,777,472	119	4,058,296	175
982,558	1,654,603	3,315,193	97	4,650,390	135
1,377,366	3,143,508	6,092,665	106	8,708,686	151
24	55				

NUMBER OF PERSONS WHO PAY LAND AND DATE TAX.

—	On 1st January, 1896	On 1st January, 1897		
	Total	Natives	Europeans	Total
Proprietors of less than 5 acres	580,674	608,373	2,701	611,074
" from 5 to 10 "	82,067	80,024	786	80,810
" " 10 " 20 "	41,691	40,548	728	41,276
" " 20 " 30 "	13,236	12,550	378	12,928
" " 30 " 50 "	9,379	8,847	450	9,297
" of more than 50 "	11,788	10,389	1,486	11,875
Total . .	738,835	760,731	6,529	767,260
Date tax only	250,719	..	..	253,280
Total . .	989,554	..	..	1,020,540

on the great perennial canals. In Lower Egypt there are 3,437,800 dependent on the perennial canals. The total area of flood irrigation is therefore 1,731,800, and of perennial irrigation 4,025,300, making a total of 5,757,100 acres.

It may be interesting to collect here the information given in the following chapters, and compare flood with perennial irrigation under all its aspects.

At present, out of a total cultivable area of 6,250,000 acres, 500,000 acres are uncultivated, 4,020,000 acres are under perennial irrigation, and 1,730,000 acres are under flood irrigation.

If the 1,730,000 acres under flood irrigation were changed into perennial irrigation, their gross yield would be increased from 11,000,000*l.* to 13,700,000*l.* per annum, or by 2,700,000*l.* The rents would be increased by 1,500,000*l.*, and the taxes by 400,000*l.* per annum.

If the whole of Egypt had been left under flood irrigation, the gross yield to-day would have been 33,000,000*l.* per annum against a gross yield of 39,000,000*l.* per annum as it is to-day, or there would have been a loss of 6,000,000*l.* per annum.

If the whole of Egypt were put under perennial irrigation, the gross yield would be 42,000,000*l.* per annum, a gain of 3,000,000*l.* per annum on the existing condition of to-day, and a gain of 9,000,000*l.* on what would have been the state of affairs if the whole country had been left under flood irrigation.

The above calculations have been massed from the detailed information in Chapters III., V. and VI., and embody information collected during a

Areas of Land in Egypt, in Acres, under Different Systems of Irrigation.

Upper Egypt												Lower Egypt	
Province	Flood Irrigation									Perennial Irrigation, Left Bank*	Total	Province	Perennial Irrigation
	Left Bank of Nile			Right Bank of Nile			Both Banks of the Nile						
	Basins	Nile Berms	Total	Basins	Nile Berms	Total	Basins	Nile Berms	Total				
Assuân . .	15,800	24,400	40,200	4,000	29,300	33,200	19,800	53,700	73,500	..	73,500	Behera .	734,400
Kena . .	172,700	18,800	191,500	113,900	37,500	151,400	286,600	56,300	342,900	..	342,900	Menufia .	351,600
Girga . .	227,900	34,000	261,900	47,600	15,500	63,100	275,500	49,500	325,000	..	325,000	Garbia .	1,077,000
Assiout. .	291,000	17,700	308,700	72,800	7,200	80,000	363,800	24,900	388,700	32,800	421,500	Kaliubai .	191,800
Minia . .	193,400	18,100	211,500	14,600	14,900	29,500	208,000	33,000	241,000	166,400	407,400	Sharkia .	568,500
Beni-Suef .	174,500	6,100	180,600	1,200	2,800	4,000	175,700	8,900	184,600	52,800	237,400	Dakhalia .	514,500
Geeza . .	80,200	57,300	137,500	25,400	13,200	38,600	105,600	70,500	176,100	6,100	182,200		
Fayûm .	..	..	..	..	..	..	..	..	..	329,400	329,400		
Total . .	1,155,500	176,400	1,331,900	279,500	120,400	399,900	1,435,000	296,800	1,731,800	587,500	2,319,300	Total .	3,437,800

	Left Bank of Nile.
Assiout	341,500
Minia	377,900
Beni-Suef	233,400
Geeza	143,600

—	Flood Irrigation	Perennial Irrigation	Total
Upper Egypt . .	1,731,800	587,500	2,319,300
Lower Egypt . .	..	3,437,800	3,437,800
Egypt . .	1,731,800	4,025,300	5,757,100

* Lower Egypt has, in addition, 500,000 acres of absolutely waste land.

special study of the subject, a study which lasted two years, and was made by a staff of twenty experts and myself, not in office, but in a tent life of twenty-four consecutive months spent in every part of Egypt from Wady Halfa to the sea.

The value of imports in 1897 was 10,603,000*l.*, of which the principal items were :—

Animals	£375,000
Skins and leather goods	174,000
Cereals, vegetables, flour	1,197,000
Provisions and drugs	390,000
Spirits, liqueurs, &c.	637,000
Rags, paper and books	145,000
Wood and coal	1,178,000
Stone, cement, glass	235,000
Dyeing materials and colours	253,000
Chemical products and perfumes	252,000
Textile goods	3,526,000
Metal and metal goods	1,129,000
Tobacco	522,000
Sundries	590,000

The principal imports are textile goods, chiefly cotton, metals or metal goods, wood, coal and cereals.

The value of exports in 1897 was 12,321,000*l.*, of which the principal items were :—

Animals	£49,000
Skins and leather goods	89,000
Cereals, vegetables, &c.	2,390,000
Sugar, provisions, &c.	646,000
Liqueurs, spirits and oils	14,000
Rags, paper and books	15,000
Wood, straw, cane, &c.	19,000
Dyeing materials and colours	13,000
Perfumery, &c.	8,000
Cotton and fibres	8,990,000
Metal goods	26,000
Sundries	62,000

It will be noted that the principal exports are cotton, cereals and sugar.

In 1897 the total ordinary revenue was 11,092,500*l.*, thus made up :—

Direct taxes—		
Land tax	£4,776,600 *	
Dates	104,500 †	
House tax	148,000	
Road tax	20,200	
		5,049,400
Indirect taxes—		
Customs	934,600	
Tobacco	1,044,800	
Octrois	217,000	
Carried forward	2,196,400	

* For 5,328,600 acres. † For 4,480,000 trees.

Brought forward	£2,196,400	5,049,400
Salt	191,500	
Fisheries	92,800	
Navigation	74,800	
Stamps and registration	40,900	
Miscellaneous	42,600	
Port dues	153,700	
Lighthouse dues	69,400	
Revenue of judicial courts	527,100	
Suakin receipts	9,600	
		3,398,800
Miscellaneous taxes—		
Interest on investments	29,400	
Military exemption fees	118,600	
Miscellaneous	107,100	
Rent of Government lands	100,300	
Contribution to pension fund	63,100	
		418,600
Railways	1,982,900	
Telegraphs	46,400	
Post office	118,800	
	77,600	
		2,225,700
		£11,092,500

The total ordinary expenditure of 1897 was 9,913,900*l.*, thus made up :—

Railways	£979,000
Telegraphs	42,000
Post office	97,200
Postal steamers	71,400
Expenses of administration	1,244,600
Justice	247,500
Public works	914,500
Customs	159,600
Octrois	33,700
Salt	56,000
Fisheries	15,800
Navigation	2,900
Ports	33,500
Lighthouses	29,600
Egyptian army	589,300
English army	84,800
Suakin	36,600
Pensions	521,300
Tribute to Turkey	665,000
Public Debt commission	31,000
Mukabala	150,000
Guaranteed debt	307,100
Privileged "	1,003,000
Unified "	2,182,900
Domain "	157,000
Daira "	258,600
	£9,913,900

At the end of 1897 the total Egyptian debt amounted to 98,107,000*l.*

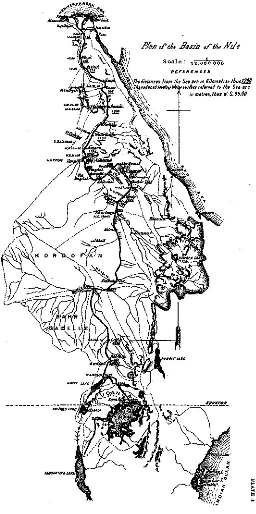
The expenditure on the more important items of the Irrigation Works, debited to the regular budget of the Ministry of Public Works, has been as follows:—

Year	New Masonry Works	Maintenance of Masonry Works	Pumping into Canals	Draining Lake Mareotis	Nile Protection Works	Temporary Dams in the Nile	Earthwork Maintenance
	£	£	£	£	£	£	£
1884	14,000	31,000	27,000	..	58,000	..	80,000
1885	13,000	31,000	31,000	..	62,000	12,000	180,000
1886	40,000	20,000	54,000	..	44,000	21,000	250,000
1887	21,000	28,000	54,000	..	49,000	7,000	250,000
1888	20,000	23,000	61,000	..	63,000	10,000	250,000
1889	38,000	27,000	60,000	..	34,000	21,000	250,000
1890	42,000	36,000	50,000	..	56,000	3,000	400,000
1891	56,000	38,000	26,000	..	38,000	3,000	400,000
1892	56,000	38,000	27,000	..	45,000	..	400,000
1893	58,000	46,000	28,000	6,000	21,000	..	400,000
1894	56,000	53,000	9,000	12,000	24,000	..	400,000
1895	53,000	52,000	500	14,000	24,000	..	400,000
1896	60,000	47,000	500	8,000	33,000	..	400,000
1897	45,000	46,000	260	9,000	32,000	..	400,000

The normal expenditure of the Irrigation Department debited to the regular budget is as follows:—

Establishment charges	£70,000
Contingent charges	25,000
New works	60,000
Maintenance of masonry works	55,000
Nile protection works	25,000
Draining Lake Mareotis	10,000
Earthwork maintenance	400,000
	£645,000

There have been, in addition to the above, large grants of money for special works, such as the 1,000,000*l.* grant of 1887 for repairing the Barrage and completing the irrigation canals of Lower Egypt; the drought grant of 800,000*l.* of 1889 for Upper Egypt; drainage grants of over 500,000*l.* for Lower Egypt; of 550,000*l.* for building subsidiary weirs at the Barrages; and finally, of 2,000,000*l.* for the Assuân dam and the Assiout weir.


Plan of the Basin of the Nile
Scale: 1/12.000.000
REFERENCES
The distances from the Sea are in Kilometres, thus 1200
The reduced levels of Water surface referred to the Sea are in metres, thus W. S. 99.00
MEDITERRANEAN SEA
Port Said
Suez
Assiout
Keneh
Assuan
1200
Wadi Halfa
1550
Abu Hamed
Berber
Kassala
KORDOFAN
BAHR GAZELLE
RUDOLF LAKE
ALBERT LAKE
UGANDA
EQUATOR
EDWARD LAKE
TANGANYIKA LAKE
INDIAN OCEAN
RED SEA

CHAPTER II.

THE NILE.

The White Nile from Lake Victoria to Lado—and from Lado to Khartoum—The Nile at Khartoum—The Nile from Khartoum to Assuân—Assuân—The Nile from Assuân to Cairo—Cairo—The Barrages and the bifurcation—The Rosetta and Damietta branches of the Nile—The catchment basin of the Nile—The rainfall in the Nile valley—Time the water takes to reach Cairo from Lake Victoria—The Nile in flood—The Nile in low supply—Navigation on the Nile—Assuân gauges corresponding to drought and inundation—Assuân and Cairo gauges in pics and kirats referred to the mean low-water level standard—Explanation of the tables accompanying the chapter—Tables.

THE Nile drains nearly the whole of North-eastern Africa, an area comprising 3,110,000 square kilometres. Its main tributary, the White Nile, has its sources to the south of Lake Victoria, and has traversed over 3500 kilometres before it is joined by the Blue Nile at Khartoum. From the junction onwards the river is known as the Nile, and after a further course of 3000 kilometres flows into the Mediterranean Sea by the Rosetta and Damietta mouths. The modulus of the Nile at Assuân is 2990 cubic metres per second, and at Cairo 2610 cubic metres per second.

Lake Victoria, covering an area of 70,000 square kilometres, is the first reservoir of the Nile. The equator passes through this lake, which lies in the region of almost perpetual rains, and receives an excessive supply of water from its western tributaries, from subsoil springs and heavy rainfall. Owing to its great extent, the fluctuations of water level are very slight. Stanley considered the discharge of the White Nile as it left Lake Victoria as one-third greater than that of the Tangouri, the principal affluent of the lake. Judging from recorded observations further down the river,* the mean discharge of the lake is probably 1000 cubic metres per second.† Shortly after leaving Lake Victoria, the White Nile descends the Ripon Falls on a width of 400 metres and a drop of 4 metres. Lake Victoria lies about 1130 metres above sea level and is 500 metres higher than Lake Albert. Between these lakes, on a distance of 480 kilometres, the White Nile (known here as the Somerset) traverses at first the succession of the swamps

* 'Le Nil, le Soudan, l'Égypte,' by A. Chelu, p. 12, Paris, 1891. The figures should be 500 and 1600 instead of 550 and 1200.

† 'Saggio idrolico sul Nilo,' by E. Lombardini, p. 35, Milano, 1864. Lombardini estimated 800 cubic metres per second. See also Plate III., Fig. 4, of his book for an interesting flood diagram at Gondokoro or Lado.

known as the Ibrahimia Lake, and then taking the character of a mountain torrent, precipitates itself into the north-eastern corner of Lake Albert. The survey of Lake Albert, which has an area of 4500 square kilometres, was made in 1877 by Mason Bey,* and he recorded the fact that the lake was 1·20 metre below its high-water level. The rainfall of that year was deficient in the whole of the Nile Valley, and the summer supply of the Nile in Egypt was the lowest of which there is any record. Lake Edward, with a probable area of 4000 square kilometres and a height above sea level of 880 metres, is a feeder of Lake Albert. After leaving Lake Albert the White Nile flows for 200 kilometres in a deep, broad arm, with scarcely any slope and scarcely any velocity, as far as Dufflé, and then after a short, troubled course tosses over the Fola Falls on a width of 90 metres, and continues as a torrent for another 200 kilometres to a short distance south of Lado. At Lado the river is 2 metres deep at low water, and only 4·50 metres deep in flood, the discharge ranging between 500 and 1600 cubic metres per second.† The regulating effect of the great lakes is well felt here. It is one of the keys for understanding the flow of the Nile, and will be dwelt on later in this book. At Lado the river is at its lowest in winter; it begins to rise about the 15th April, and reaches its maximum between 15th and 30th August.‡

From Lado to Bôr, a distance of about 120 kilometres, the river keeps in one channel and has a rapid fall, while from Bôr to the mouth of the Gazelle River, on a further reach of 380 kilometres, the river divides into numerous channels and has a very feeble slope. The main channel is known as the Bahr el Gebel (the mountain stream) and is the one always used for navigation. In this reach are the "sadds" or dams of living vegetation, which at times are capable of barring the surface and completely blocking navigation. The Gazelle River joins the White Nile on its left bank and has a feeble discharge in summer, though occasionally it exceeds the Bahr el Gebel in flood.

At the junction of the Gazelle River and While Nile is a lake of an area of some 150 square kilometres in summer. In years of scanty rainfall, all this flat, marshy part of the river acts as an evaporating basin and a source of loss to the Nile. The waters of the river likewise become polluted here with decaying vegetable matter, which at certain times of the year imparts a green colour to the Nile as far north as Cairo. A hundred kilometres below the Gazelle River the White Nile is joined by the Saubat river on its right bank. During flood this river has a discharge nearly equal to that of the White Nile above the junction, while in summer it has a feeble

* Khedivial Geographical Society's Journal, Cairo, 1877.

† See footnotes on preceding page.

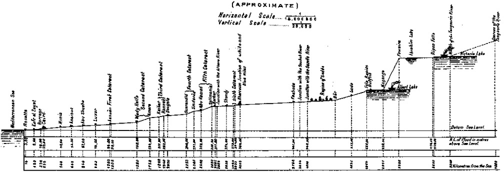
‡ See second footnote on preceding page. I take this opportunity of recording my obligations to the late Sir Samuel Baker for much information about the White Nile and its tributaries.

Longitudinal Section of the Nile.

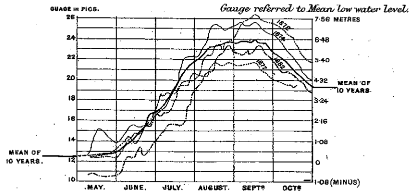
(APPROXIMATE)

Horizontal Scale ...... $\frac{1}{15{,}000{,}000}$

Vertical Scale ...... $\frac{1}{20{,}000}$



KHARTOUM gauge diagram 1874, 1878, 1877, 1882 and average of 10 years 1874 to 1883.



The Khartoum gauge stood on the Blue Nile about 5 kilometres above the Junction at Khartoum — Distance from sea about 3000 kilometres. The 1878 gauge was much higher than the 1874 gauge, at Khartoum, than at Assuan. The Atbara must have made the difference. The 1874 flood was an early, torrential flood; it fell early, and was followed by a fairly low summer. The 1878 flood was a late one, (from the great basin regions) it fell late, and was followed by the highest summer on record.

discharge and is occasionally quite dry. From the junction of the Saubat to Khartoum, on a length of 900 kilometres, the White Nile has a mean width of 1700 metres, a depth varying from 2 metres in low supply to 7·5 metres in flood, and is a sluggish stream. The action of the current is always on the right bank, owing to the prevailing north-west winds, and this action is continued during the whole of the remaining course of the river as far as the sea. The soil from the Saubat river to Khartoum is light and friable, and the White Nile, in spite of its moderate velocity, has a width 160 times its depth in flood.

At a point 3009 kilometres from the sea and 390 metres above it, is the town of Khartoum, where the Blue Nile from Abyssinia joins the White Nile. The Blue Nile has its sources in the mountains of Abyssinia, where Lake Tsana—with an area of 3000 square kilometres, and height above sea level of 1780 metres—is another reservoir of the Nile. The Blue Nile has a length of 1350 kilometres. This river is comparatively clear in summer, but during flood, i.e. from the beginning of June to the end of October, it is of a reddish-brown colour, highly charged with alluvium. The Khartoum Nile gauge, which was read from 1869 to 1883, used to stand on the Blue Nile about 5 kilometres above its junction with the White Nile, and its recorded readings are not exact records of the Nile. In flood the discharges of the two rivers are nearly equal, but in summer the White Nile is the more important source of supply. The Nile here has a mean range of 6·50 metres between high and low supply, with a maximum of 7·80 metres and a minimum of 5·30 metres. From comparison with the Assuân gauge and observed discharges referred to the Khartoum gauge, it is probable that the high supply varies between 11,100 and 5200 cubic metres per second, with a mean discharge of 8000 cubic metres per second, while the low supply varies between 1500 and 320 cubic metres per second, with a mean discharge of 550 cubic metres per second.* April is the lowest month and September the highest.

At a distance of 86 kilometres downstream of Khartoum is the Sixth Cataract. Here the Nile descends 6 metres on a length of 18,000 metres. At a distance of 320 kilometres from Khartoum the Nile is joined by the Atbara river. This latter is another stream fed by the Abyssinian torrents, and though dry in summer is a considerable river in flood. Heavily charged with volcanic detritus, it provides the greater part of the rich fertilising mud which the Nile carries in flood. The Atbara has a range of 8 metres, and from calculations and comparisons, I estimate that its floods range between 4900 and 1600 cubic metres per second, with a mean high flood of 3100 cubic metres per second. It is in flood from July to October,

* 'Géographie Universelle,' by E. Reclus, vol. x. p. 77, Paris, 1884. Linant Pasha made the high flood discharges of the White and Blue Niles 5000 and 6100 cubic metres per second, and the low summer discharges 300 and 160 respectively.

with its ordinary maximum in August. Below the Atbara junction the Nile has no tributary, and flows throughout its 2700 kilometres to the sea, a solitary stream. Traversing one of the greatest deserts on the globe, it is the sole source of life and vigour to whatever exists on its banks.

Twenty-four kilometres downstream of the Atbara junction is Berber, and 45 kilometres downstream of Berber is the beginning of the Fifth Cataract, which has a length of 160 kilometres and a drop of 63 metres, with three principal rapids, the Solimania, Baggâra and Mograt. The village of Abu Hamed is situated at the foot of this cataract. Between Abu Hamed and Dongola is the Fourth Cataract, which begins at a point 97 kilometres downstream of Abu Hamed, and has a length of 110 kilometres with a drop of 49 metres. In this series of rapids are the Um Dâras and Guerendid. Between the Fourth and Third Cataracts is a reach of 313 kilometres on a slope $\frac{1}{12000}$. On this reach is the town of Dongola. The Third Cataract has a length of 72 kilometres and a drop of 11 metres, with the Hannek and the Kaibar rapids, surveyed and levelled by De Gottberg in 1857. Upstream of the Hannek rapid, on the left bank of the Nile, is the termination of the long depression in the desert which goes by the name of the Wady el Kab, and is considered by many as lower than the Nile valley.* Between the Third and Second Cataracts is an ordinary reach of 118 kilometres. West of this part of the Nile are the Selima Wells.†

The Second Cataract, known as the "Batn el Haggar," has a length of 200 kilometres and a drop of 66 metres, with the rapids of Amàra, Dal, Semna and Abka. At Semna are the rocks where Lepsius discovered the Nile gauges cut by one of the Pharaohs some 4000 years ago.‡ The Nile flood recorded there is 8 metres higher than any flood of to-day. As the Nile at Semna could be very easily barred by a dam, it struck me when I was there in 1892, that probably King Amenemhat (of Lake Mœris fame), had tried to bar the river with a dam in the hope of creating a reservoir. At Wady Halfa, near the foot of the Second Cataract, a masonry gauge divided into metres has been erected and read since 1877. Its accidental zero is R.L. 116·69, and the mean low-water level or true zero is R.L. 117·89.§ Between the First and Second Cataracts, the Nile has a length of 345 kilometres and a slope of $\frac{1}{12500}$. The mean width of the river is 500 metres, and the mean depths in flood and summer are 9 and 2 metres. The velocity in summer falls to 50 centimetres per

* 'Géographie Universelle,' vol. x. p. 457.

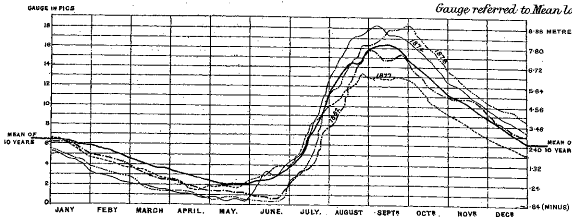
† The rocks at Selima are limestone.

‡ Mr. Coteril made a section of the river here for Count de la Motte.

§ I have adopted everywhere the mean low-water level as the natural zero of the gauge. Everything above is +, and below −. All the tables in this book are referred to the mean low-water level as zero.

ASSUAN gauge diagram 1874, 1878, 1877, 1882 & average of 10 years 1874 to 1883.

Gauge referred to Mean low water R.L. 85·00 m.



Assuan Gauge zero 84·16 metres above mean sea – 1204 kilometres from sea (Rosetta Branch)

1874, 1878, Highest floods on record. Inundations
1877, Lowest flood. Famine in Upper Egypt.

1874 Maximum early in September, not so bad for the country as 1878 with maximum in October.

The mean of the 10 years just above 16 pics for 20 days – favourable in every way.

second, and rises to 2 metres per second in flood. The river in this reach is generally within sandstone, and the greater part is provided with gigantic spurs on both banks. These spurs perform the double work of collecting soil on the sides in flood and training the river in summer. They were probably put up by the great Rameses 3000 years ago, as some of the most massive of them have evidently been constructed to turn the river on a curve out of its natural channel on to the opposite side in order to secure deep water in front of his temple of Jerf Husain ("Jerf" means steep, scoured bank). The spurs have been constructed with care, and as the courses of roughly dressed stone can be examined at fairly low water (I have never seen them at absolutely low water), it is evident that there has been no great degradation of the bed during the last 2000 or 3000 years. The First or Assuân Cataract has a drop of 5 metres on a length of 5 kilometres.

From Khartoum to Assuân, on a total length of 1809 kilometres, there are 565 kilometres of so-called cataracts with a total drop of 200 metres, and 1244 kilometres of ordinary channel with a total drop of 95 metres.

At the foot of the First Cataract, opposite the town of Assuân, on the Island of Elephantine, has stood a Nile gauge from very ancient times. An officer belonging to the Roman garrison in the time of the Emperor Severus marked an extraordinary high flood on the gauge. The maximum flood mark at the time of the visit of Napoleon's French savants was, however, 2·11 metres higher than the above. As the middle of Severus' reign was A.D. 200, and the visit of French savants A.D. 1800, they concluded that the bed and banks of the Nile had risen 2·11 metres in 1600 years, or 0·132 metre per 100 years. The new gauge, divided into cubits and twenty-fourths, was erected in 1869, and has been recorded daily since then (a cubit = 54 centimetres). Its accidental zero is R.L. 84·16. The mean low-water level or true zero is R.L. 85·00.

Recently Nilometers of the Ptolemaic and Roman periods have been discovered by Captain Lyons, R.E., and Dr. L. Borkhardt at Kubosh, Taifa, Edfu and Esna. Also very complete information has been obtained by them of the previously known gauges at Philæ and Elephantine. They are publishing a monograph on the subject, which will throw considerable light on the behaviour of the Nile during the last 2000 years. Ventre Pasha, in a paper read before the Khedivial Geographical Society, calculates a rise of ·096 metre per century, from recently discovered flood marks at Karnak dating from the time of Rameses.

From Assuân to the Barrage the length of the river is 973 kilometres in summer and 923 in flood. The slope in summer is $\frac{1}{13000}$ and in flood $\frac{1}{12200}$. The mean fall of the valley is $\frac{1}{10800}$. The slopes vary in the

different mean reaches, the least being $\frac{1}{14800}$ in the Kena Mudiria, and the greatest $\frac{1}{11400}$ in Beni-Suef. In a high flood, with a rise of 9 metres at Assuân, the rise in Kena will be 9·5 metres and only 8·2 in Beni-Suef. Neglecting spill channels, we may state that in a high flood the mean area of the section of the Nile is 7500 square metres and the mean width 900 metres. In the Kena Mudiria the area is 7000 square metres and the width 800 metres, while in Beni-Suef the mean area is 8000 square metres and the mean width 1000 metres. Speaking generally, it may be stated that where the Nile valley is narrow the slope of the river is small, its depth great and width contracted; while where the valley is broad the slope is great, the depth small and the width enlarged. The mean velocity in flood ranges between 2·0 metres and 1·0 metre per second, while the velocity in summer varies from ·3 metre to ·7 metre per second. We may say that the Nile in soil has a natural section whose width in flood is 110 times its depth, while its mean velocity is 1·50 metre per second.

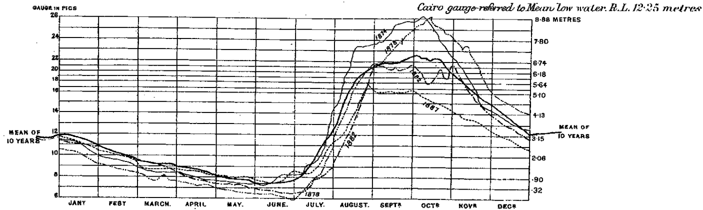
The natural canals, which take off the river and which never silt, have a mean velocity of some 70 centimetres per second, while the proportion of width to depth is about 12 to 1. Artificial canals of this section do not silt if their velocities are 80 centimetres per second.

On Roda Island, opposite Cairo, has stood a gauge from the earliest times. It has been frequently reconstructed. The present gauge is reputed to have been erected in A.D. 861, with its zero at the same level as a more ancient one whose readings have been preserved since A.D. 641. When the gauge was constructed, a reading of 16 cubits meant the lowest level at which flood irrigation could be ensured everywhere. The level to-day is 20½ cubits on the gauge, and the difference between them is 1·22 metre. As 1026 years have elapsed since the construction of the gauge it means a rise of 12 centimetres per 100 years. This is slightly under the rise calculated at Assuân.

The following table gives the means of the maximum flood and low-water levels per century :—

	Flood	Low Water	Difference
7th century	17·5 R.L.	11·5 R.L.	6·0
8th "	17·4 "	10·8 "	6·6
9th "	17·5 "	11·5 "	6·0
10th "	17·5 "	11·3 "	6·2
11th "	17·5 "	11·6 "	5·9
12th "	17·7 "	12·2 "	5·5
13th "	17·7 "	11·4 "	6·3
14th "	17·9 "	11·1 "	6·8
15th "	18·2 "	11·8 "	6·4
16th "	18·4 "	11·9 "	6·5
17th "	18·8 "	11·8 "	7·0
18th "	19·1 "	11·8 "	7·3
19th "	19·5 "	12·3 "	7·2

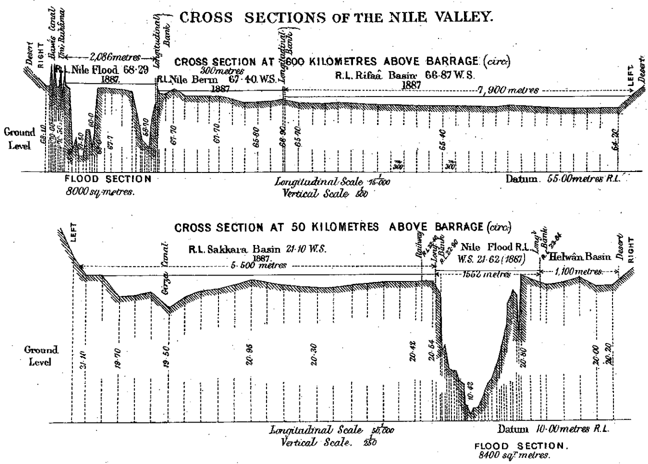
CAIRO gauge diagram 1874, 1878, 1877, 1882 & average of 10 years 1874 to 1883.



Cairo gauge zero unknown .. 27 Kilometres above Barrage.

The Roda gauge is no reliable record in summer & winter owing to the Barrage afflux. The gauge of 1878 would have been much higher than that of 1874, had not the left Nile bank been breached at Gizeh in 1878 just above the gauge.

CROSS SECTIONS OF THE NILE VALLEY.



It is evident from the above that the head of the Delta, or the bifurcation of the Nile, was much nearer to Cairo in early days than just now, and the last three centuries have seen great changes. The fall of water-surface is very considerable at every bifurcation, and the difference between mean high and low supply at the Barrage to-day is 6·0 metres against 7·2 metres at Cairo. Judging from the above figures, I should say that from the 7th to the 12th century the bifurcation was gradually approaching Cairo, while since the 12th it has been receding.

At Assuân the Nile has a mean range of 7·90 metres between high and low supply, with a maximum of 9·80 metres and a minimum of 6·40 metres. The high supply varies between 13,200 and 6500 cubic metres per second, with a mean of 10,000 cubic metres per second; while the low supply varies between 210 and 1300 cubic metres per second, with a mean of 410 cubic metres per second. September is generally the highest month, and May the lowest. The mean low-water level is R.L. 85·00.

At Cairo the Nile has a mean range of 7·00 metres, with a maximum of 9·6 metres and a minimum of 5·3 metres. The high supply varies between 12,000 and 4800 cubic metres per second, with a mean of 7600 cubic metres per second; while the low supply varies between 1300 and 170 cubic metres per second, with a mean of 380 cubic metres per second. October is the highest month, and June the lowest. The mean low-water level is at R.L. 12·25.

At the Barrages the Nile bifurcates into the Rosetta and Damietta branches. They are both of the same length, namely, 236 kilometres. The following table gives details of discharges at Cairo, and at the heads of the two branches :—

Locality	Channel	Season	Discharges in Cubic Metres per Second		
			Maximum	Minimum	Mean
Cairo . .	Nile.	Summer	1,320	160	410
		Flood	11,900	4,650	7,200
		Winter	2,300	960	1,350
Barrages . .	Rosetta branch. .	Flood	6,500	2,900	4,100
	Damietta branch .	Flood	4,600	1,500	2,400

During winter and summer, regulation at the Barrages interferes with the natural discharges of the two branches. The Damietta branch is gradually silting up and decreasing in size, while the Rosetta branch is gradually scouring out and increasing in section. This subject will be

returned to in Chapters X. and XI. The mean width of the Rosetta branch is 500 metres, and the mean area of the section is 4000 square metres. The mean width of the Damietta branch is 270 metres, and the mean section 2700 square metres. The mean velocity of the floods ranges between 80 centimetres and 1·60 metre per second. In summer, nowadays, the branches are practically dry, as all the water is sent down the canals. The flood slope in both branches is $\frac{1}{13000}$ and the summer slope $\frac{1}{20000}$. It may be noted here that at Cairo the girder bridge at Kasr el Nîl is 403 metres between the abutments, while the smaller bridge is 178 metres, making a total width of 581 metres. At the Kafr Zyat bridge, on the Rosetta branch, the flood line is about 530 metres, while the Benha bridge on the Damietta branch is 285 metres wide. The average depth of water in the branches in full flood may be taken as 7 metres.

The approximate areas of the catchment basins of the Nile and its tributaries are as follows:—

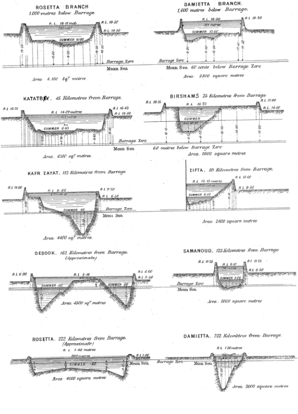
	square kilometres
1. The White Nile at the Ripon Falls	260,000
2. The White Nile between the Ripon and Fola Falls	130,000
3. The White Nile between the Fola Falls and Lado	60,000
4. The White Nile between Lado and the Saubat junction	190,000
5. The Gazelle river	220,000
6. The Arab river	340,000
7. The Saubat river	130,000
8. The White Nile between the Saubat junction and Khartoum	320,000
9. The Blue Nile	310,000
10. The Atbara and Gaash	240,000
11. The Desert north of Khartoum	910,000
The Nile	3,110,000

The rainfall about Lakes Victoria and Albert and about Lado and the upper halves of the Saubat, Blue Nile and Atbara may be taken as 1½ metre per annum. In the eastern half of the Gazelle river, the lower half of the Saubat, and middle third of the Atbara, 1 metre per annum may be taken as the rainfall. The western half of the Gazelle river has probably 50 centimetres per annum, while the Arab river and tail portions of the White and Blue Niles and the Atbara cannot have more than 25 centimetres per annum. From Berber northwards there is a very scanty rainfall indeed, and the country is considered rainless. Applying these rainfalls to the catchment basins, we obtain the total mean annual rainfall in the Nile valley as follows.*

* It may be noted here that more recent observations on rainfall nearly everywhere reduce the quantity of rain reported by the earlier travellers.

CROSS SECTIONS OF THE NILE BRANCHES.

Scale, Long^l $\frac{1}{12,000}$
Vert^l $\frac{1}{600}$



	square kilometres		metres		cubic metres
1.	260,000	×	1·5	=	390,000,000,000
2.	130,000	×	1·5	=	195,000,000,000
3.	60,000	×	1·5	=	90,000,000,000
4.	190,000	×	1·0	=	190,000,000,000
5.	220,000	×	0·75	=	165,000,000,000
6.	340,000	×	0·25	=	85,000,000,000
7.	130,000	×	1·5	=	215,000,000,000
8.	320,000	×	0·30	=	96,000,000,000
9.	310,000	×	1·5	=	465,000,000,000
10.	240,000	×	1·25	=	300,000,000,000
11.	910,000	×	0·10	=	91,000,000,000
	3,110,000	×	0·74	=	2,282,000,000,000

If we examine the plan and note the lengths of the different rivers and their slopes, it will be evident that the Saubat, the Blue Nile and the Atbara are the ruling factors in flood, while the White Nile is the ruling factor during the remainder of the year.

We have next to consider the times of rainfall. In the great lake regions the rainy season lasts from February to November, with one maximum in April and another in October. At Lado the rains continue from April to November, with a maximum in August. In the valley of the Saubat the rainy season is from June to November, with a maximum in August. It rains from April to September in the valley of the Gazelle river. From July to September is the rainy season at Khartoum, and from July to August in Kordofan and Darfûr. In Abyssinia, there are light rains in January and February, and heavy rains from the middle of April to September, with a maximum in August. August is the centre of heavy rainfall everywhere except at the great lakes.

The time the water takes to travel down the different lengths of the river may be found from discharge, velocity and slope calculations, and from comparisons between the fluctuations of the Lado, Khartoum, Assuân and Cairo gauges. I calculate that it takes the water 8 days to travel from Lake Victoria to Lake Albert, and 5 days from Lake Albert to Lado. There is not much difference between high and low supply in these reaches. It takes the water 36 days to traverse the distance between Lado and Khartoum in low supply, and 20 days in flood. Between Khartoum and Assuân the times are 26 days in low supply and 10 days in flood. Between Assuân and Cairo, we have 12 days in low supply and 5 days in flood; while between Cairo and the sea, we have 3 days and 2 days respectively. It takes 90 days for the water in low supply to reach the sea from Lake Victoria, while in flood it takes 50 days.

The Blue Nile traverses the distance between its sources and Khartoum in some 17 days in low supply and 7 days in flood. The Atbara takes 5 days in flood, and the Saubat cannot take a much longer time.

Referring to the map and keeping all the above facts in mind, an

average year in the Nile basin may be thus described. The heavy rains near Lado begin in April and force down the green water of the swamp regions. About the 15th April the White Nile at Lado begins to rise, and by the 1st September has reached its maximum. In this interval the discharge has risen from 500 cubic metres per second to 1600 cubic metres per second. This rise is felt at Khartoum about the 20th May, and at Assuân about the 10th June. The green water announcing this rise is seen at Cairo about the 20th June. In an average year, on the 20th May, the White Nile discharge of 300 cubic metres per second at Khartoum begins to increase, and goes on gradually increasing to the 15th or 20th September, when the maximum floods of the White Nile and Saubat reach Khartoum and attain a discharge of 4500 cubic metres per second. The low-water discharge of the Blue Nile is 160 cubic metres per second, and about the 5th June it begins to rise fairly quickly, and reaches its ordinary maximum of 5500 cubic metres per second by about the 25th August. Owing to the two floods rarely being contemporary, the ordinary maximum flood of 8000 cubic metres per second is generally on the 5th September. The red muddy water of the Blue Nile reaches Assuân about the 15th July, and Cairo about the 25th July. Once the red water begins to appear the rise is rapid, for the Atbara is in flood shortly after the Blue Nile, and its flood waters rise with great rapidity. The Atbara would come down much earlier than it does were it not that a whole month is expended in saturating the desert and its own dry sandy bed. The Atbara flood begins in the early part of July and is at its highest about the 20th August, reaching an ordinary maximum of 3400 cubic metres per second, and occasionally an extraordinary maximum of 4900 cubic metres per second.

It is owing to the earliness of the Atbara high flood and the lateness of the White Nile high flood, that the ordinary maximum discharge of the Nile at Assuân is only 10,000 cubic metres per second. This is generally on the 5th September. When the White Nile is weak, the maximum at Assuân is reached before or on the 5th September; when the White Nile is strong, the maximum is reached about the 20th September. An early maximum at Assuân is always followed by a low summer, while a late maximum is nearly always followed by a high summer supply. Only once has this rule been broken, and that was in 1891, when there were two maxima—one on the 4th September and another on the 27th. In this year there must have been an extraordinary fall of rain in Abyssinia in September, for the flood of the 27th September was very muddy, while as a rule the river at Assuân is very muddy in August, less so in September, and very much less so in October, when the White Nile is the ruling factor in the supply of the river.

If the White Nile happens to be in very heavy flood late in September,

and the September rains in Abyssinia are also very heavy, an extraordinary flood passes Assuân at the end of September, and is disastrous for Egypt. This happened in 1878. Tables III. and IV. contain details of this flood, of the minimum flood year 1877, and the mean of the 20 years from 1873 to 1892.

At Assuân the Nile enters Egypt, and it now remains to consider it in its last 1200 kilometres. The mean minimum discharge at Assuân is 410 cubic metres per second, and is reached about the end of May. The river rises slowly till about the 20th July, and then rapidly through August, reaching its maximum about the 5th September, and then falling very slowly through October and November. Table III. gives every detail of a maximum, minimum and mean year. The deep perennial irrigation canals take water all the year round, but the flood irrigation canals are closed with earthen banks till the 15th August, and are then all opened. These flood canals, of which there are some 45, are capable of discharging 2000 cubic metres per second at the beginning of an ordinary year, 3600 cubic metres per second in a maximum year, and have an immediate effect on the discharge of the Nile. The channel of the Nile itself and its numerous branches and arms consume a considerable quantity of water (the cubic contents of the trough of the Nile between Assuân and Cairo are 7,000,000,000 cubic metres): the direct irrigation from the Nile between Assuân and Cairo takes 50 cubic metres per second, 130 cubic metres per second are lost by evaporation off the Nile, and 400 cubic metres per second by absorption. Owing to all these different causes, there is the net result that, from August 15th to October 1st, the Nile is discharging 2400 cubic metres per second less at Cairo than at Assuân. During October and November the flood canals are closed, and the basins which have been filled in August and September discharge back into the Nile; and in October the Nile at Cairo is discharging 900 cubic metres per second in excess of the discharge at Assuân, and 500 cubic metres per second in November. An examination of Tables III. and IV. will show this very clearly.

The ordinary minimum discharge at Cairo is 380 cubic metres per second, and is attained on the 15th June; the river rises slowly through July and fairly quickly in August, and reaches its ordinary maximum on the 1st October, when there is no irrigation in the basins and the discharge from the basins is just beginning. The ordinary maximum discharge at Cairo is about 7600 cubic metres per second. Through October the Nile at Cairo is practically stationary, and falls rapidly in November.

North of Cairo are the heads of the perennial canals which irrigate the Delta proper. These canals, with their feeders lower down, discharge 1200 cubic metres per second, and the ordinary maximum flood at Cairo

of 7600 cubic metres per second is reduced by this amount between Cairo and the sea. Of the 6400 cubic metres per second which remain, 4100 cubic metres per second find their way to the sea down the Rosetta branch, and 2300 cubic metres per second down the Damietta branch. During extraordinary floods, the Damietta branch has discharged 4300 cubic metres per second, and the Rosetta branch 7000 cubic metres per second.*

We have so far considered the Nile in flood; it now remains to quickly dispose of the low supply. After reaching its maximum, the Atbara, which is a torrential river, falls more rapidly than others, and by the end of October has practically disappeared; after the middle of September the Blue Nile falls quickly, while the White Nile, with its large basin, gentle flow and numerous reservoirs, falls very deliberately. The mean discharge of the White Nile at Lado in an ordinary year, at the time of low supply, is 550 cubic metres per second. By the time it reaches Khartoum it is reduced by evaporation to some 350 cubic metres per second. The ordinary low supply of the Blue Nile is 190 cubic metres per second, giving an ordinary low supply to the Nile at Khartoum of 540 cubic metres per second. The Atbara supplies nothing. Between Khartoum and Assuân there is a further loss from evaporation and irrigation of 130 cubic metres per second, and the mean low supply delivered at Assuân is 410 cubic metres per second. In very bad years, the discharge at Assuân has fallen to 210 cubic metres per second, which would probably mean 340 cubic metres per second at Khartoum; and adopting Linant Pasha's proportion, the White Nile would be discharging 220 cubic metres per second, and the Blue Nile 120 cubic metres per second. As the White Nile at Lado never discharges much under 500 cubic metres per second, the loss on that river under the most unfavourable conditions is about 300 cubic metres per second, while the loss on the Blue Nile cannot be more than 50 cubic metres per second. Summing up, therefore, we may state, in a very bad summer the Nile sources supply 660 cubic metres per second, the discharge at Khartoum has dwindled to 340 cubic metres per second, and at Assuân to 210 cubic metres per second. The moment the daily fall of the river becomes less than the daily loss by evaporation, all the small ponds and pools cease to aid the stream, and if they are very extensive, as they are south of Fashoda, they diminish the discharge considerably by their large evaporating areas. The six cataracts of the Nile, with their numerous raised sills and moderate floods, lengthen them out, but when the months

* The Barrage gauge is the up-stream gauge of the Rosetta branch Barrage. Its zero is 10 metres above sea level, and its mean low-water level 11·00. Owing to the Nile here dividing into two branches, this mean gauge is not capable of reference to other gauges on the Nile, as it is affected by the bifurcation.

of real low discharge have come, the great reservoirs of the Nile are the sole sources of supply.

The only hindrance to the navigation of the Nile below the First Cataract is the want of water at low Nile. Between Assuân and the Barrages, boats drawing under 1 metre of water can ply during the summer, except in very low years, when boats drawing 0·70 metre ply with difficulty. During the winter, boats drawing 2 metres of water can ply easily. The Damietta branch is navigable by all classes of boats from August 1st to March 1st, after which date navigation is stopped. Navigation between Mansourah and Damietta is open throughout the year to boats drawing less than 1½ metre of water, and to boats drawing over 1½ metre for eight months. The bar at the mouth of the Damietta branch varies, but boats drawing 2 metres can pass ordinarily, except in the early stages of the flood, when the sand-bar blocks the channel for some fifteen days. The Rosetta branch is closed to navigation from March 1st to August 1st, between the Barrage and a point 20 kilometres south of Kafr Zyat; between this latter point and Rosetta there is always enough water for boats drawing 1½ metre. Boats drawing 2 metres can ordinarily pass the bar at the mouth of this branch; during flood, however, the bar behaves very badly and makes the passage very uncertain. Since the breeze is generally from the north-west, while the current flows northwards, navigation on the Nile is very easy and pleasant. From August to January the locks at the Barrages are open, and boats of any length can pass, provided their beam is not too great. During flood the 12-metre wide locks are open at both Barrages. I am obliged to Mr. J. Cotterill, of the Egyptian Railways, for the following information.

On the main Nile, the openings for boats at the Naga Hamedi bridge is 30·2 metres, at the Kasr el Nîl bridge at Cairo it is 22·8 metres, and at Embabeh 24·4 metres. On the Rosetta branch, the Barrage lock is 12 metres wide, the old Kafr Zyat bridge opening is 24·3 metres wide, and the new 25·5 metres, and the Desouk bridge is 26 metres. On the Damietta branch the Barrage lock is 12 metres wide, the Benha new bridge is 25·3 metres, the old is 18·4 metres, and the Mansura bridge 24·4 metres.

The irrigation of Egypt is gauged by the height of the river at Assuân. When the maximum rise of the river is 6·50 metres, there will be famine in parts of Upper Egypt; between 6·50 and 7·25, there will be indifferent irrigation; between 7·25 and 7·75, difficulty in irrigation in certain tracts; between 7·75 and 8·25, perfect irrigation; between 8·25 and 8·75, floods; and above 8·75, inundation and harm.

It may be useful to give here the readings in pics and kirats on the Assuân and Cairo gauges, corresponding to the gauges in metres referred to mean low-water level, which are the gauges uniformly employed in this book.

Gauge referred to Mean Low-water Level in Metres	Assuân		Cairo	
	Pics	Kirats	Pics	Kirats
−·50	0	15	..	..
0	1	14	..	..
0·50	2	12	7	8
1·00	3	10	8	5
1·50	4	8	9	1
2·00	5	6	9	23
2·50	6	4	10	19
3·00	7	2	11	17
3·50	8	1	12	15
4·00	9	0	13	15
4·50	9	22	14	16
5·00	10	20	15	17
5·50	11	18	17	11
6·00	12	16	19	8
6·50	13	14	21	4
7·00	14	12	22	12
7·50	15	11	23	10
8·00	16	9	24	8
8·50	17	7	25	7
9·00	18	6	26	5

At the Assuân gauge 1 pic = 54 centimetres. At Cairo the pics above 22 and below 16 are about 54 centimetres each, while between 16 and 22 the pics are 27 centimetres each. There are 24 kirats in each pic.

As already stated, all gauges and discharges in this book have been referred to one uniform standard, and that the mean low-water level of the Nile. The mean high-water level and the mean low-water level were both available.* In Egypt the mean high-water level varies very considerably, whether we take it in August and the early part of September, when the basin canals are running full supply, or in the latter half of September, when the canals are running only half supply, or in October, when the basins are discharging back into the Nile. Early and quick rising floods have a different series of levels from slow and late floods; while again, the recent works carried out in Upper Egypt by Colonel Ross have so increased the discharging capacity of the canals that the flood gauges have been appreciably affected. All this points to the conclusion that the mean high flood is no satisfactory standard. The mean low flood, on the other hand, is much less liable to change, and is very fairly constant from year to year. High floods are certainly followed by scouring out of the bed, and low floods by a silting up of the channel, but the changes are very moderate

* 'Perennial Irrigation and Flood Protection in Egypt,' by W. Willcocks, Cairo, 1894; and 'Guida del idrologia fluviale,' p. 58, by Lombardini, Milan, 1870.

compared to those in high flood. I have chosen the mean low-water level as the line of reference, and all gauges mentioned in this book are referred to it. From the mean of twenty years' observations, this level was found to be at Assuân R.L. 85 metres. By observations along the Nile generally, and by calculations at Cairo, I have fixed it at all important places north of Assuân. It was on this system that the ancient Egyptian engineers worked the Nile. They, however, chose the mean high-water level during the early part of the flood as their standard of reference, and consequently made the so-called cubits in the flood reaches of the Cairo gauges half cubits. This means a discharge of 1600 cubic metres per second, and fairly represented the discharges of the basin canals in flood. When it is considered that the level of the Nile valley is raised by about 12 or 13 centimetres per 100 years, it will be seen that the old Cairo gauge, which was a living record 1500 years ago, is to-day a meaningless anachronism. It has also to be compared with the Assuân gauge, which was erected in Ismael Pasha's time, with an arbitrary zero some 90 centimetres below mean low-water level, and which may be reading 17 cubits while Cairo may be recording 25 cubits. The Cairo gauges in winter and summer are no records of discharge, as the afflux from the Barrage affects them. To find the discharge at Cairo during these months, I have added those of the Rosetta and Damietta branches and the Delta canals up-stream of the Barrage. When the Nile falls below mean low-water level, the gauges are recorded as minus quantities.

Discharge sites having been chosen for the Assuân, Assiout and Cairo gauges on the Nile, a continuous series of surface velocity observations, cross sections and slope measurements were made by me during 1892 and 1893, and the resulting discharges recorded. Curves of discharge were drawn, and referred to the gauges of twenty years, and modified until finally a curve was found which suited any year whether it were a maximum or a minimum. In connection with this subject, it must be remembered that the Nile bed is raised by silt during low floods and scoured out during high floods, and that consequently August and September discharges vary considerably at times from October and November discharges for the same gauge. In addition to this, it must also be borne in mind that the slope of water surface, and consequently the discharge of a flood during the rise, is far greater than during the fall for the same gauge. Indeed, the Nile often discharges more when it is 30 centimetres below its maximum, and rising fast, than when it has reached its maximum and begun to fall. It is owing to this fact that we often see the discrepancy of the Assuân gauge reaching its maximum a day before Halfa, which is 360 kilometres higher up the river. The discharge depends on gauge and slope, and the gauge only records one element.

Before leaving this subject I should like to record here that, considering

how the Nile in high flood scours out its bed, and in a low flood silts it up, it is probable that it is owing to the fact that low floods are more numerous than high ones that the silting process gains on the scouring out, and we have a rise of the bed per century. This rise of the bed is accompanied by a rise of the general level of the Nile valley where there is basin irrigation.

The accompanying Tables I. to XIV. embody a mass of information in a compact form.

Table I. gives the reduced level of the mean low-water level of the Nile at various points between Cairo and Assuân. The officers of the Reservoir Survey carried a line of levels from the Barrage to Wady Halfa. These levels differ in places from those according to the inspectors of irrigation. Both are given. If, for example, it is known that the water surface at any time of the year at Assiout, according to the inspectors of irrigation, say, is R.L. 50·80, by looking at the table we see that the mean low-water level is 45·05. We know, therefore, that the gauge is 5·75, and by turning to Table II. we see that the discharge of the river is 5475 cubic metres per second.

Table II. gives discharges of the river corresponding to the gauges referred to mean low-water level. In the reach between Esna and Kena the table gives discharges very slightly in excess of the truth, and between Assiout and Beni-Suef slightly under the truth; but taken all round it is a reliable, practicable table, calculated from the means of hundreds of discharges, and prepared with the greatest care and diligence.

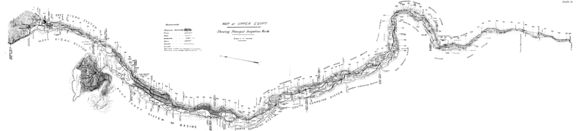
Table III. gives 5 daily gauges and discharges of the Nile at Assuân and Cairo for a minimum year, a maximum year, and the mean of 20 years. Referring to the table, it will be seen that the maximum discharge of the Nile at Assuân was on the 30th September, 1878, and amounted to 13,200 cubic metres per second. The minimum discharge was on the 25th June of the same year, and amounted to barely 160 cubic metres per second.

Table IV. gives the same information by months and years.

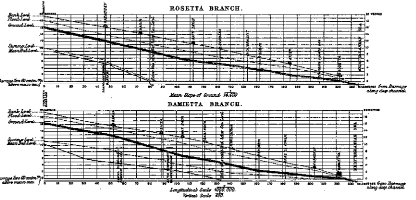
Table V. gives the slope of water surface of the Nile in flood and in summer between Assuân and Cairo. Owing to the more winding track of the low supply than of the flood waters, the length of the Nile measured down the centre line of the summer channel is 948 kilometres, and of the flood 900 kilometres. The slope in summer is $\frac{1}{13000}$, and in flood $\frac{1}{12200}$.

Table VI. gives the areas of cross sections of the Nile from Assuân to Cairo.

Table VII. gives the cubic contents of the trough of the Nile, and Table VIII. gives the widths of water surface. These three tables are needed for any calculations to ascertain losses by absorption, evaporation and consumption of water between Assuân and Cairo, in case reservoirs


MAP OF UPPER EGYPT
Showing Principal Irrigation Works
REFERENCES
EAST GIZAH SYSTEM
WEST GIZAH SYSTEM
SYSTEM OF BASINS
NORTH SOHAGIAH SYSTEM
SOUTH SOHAGIAH SYSTEM

LONGITUDINAL SECTIONS OF ROSETTA AND DAMIETTA BRANCHES OF THE NILE.



Flood level down Damietta Branch is in middle reaches one Metre above that in Rosetta Branch.

are constructed and the water is sent down the Nile to be utilised far from the reservoir. They are also essential in all calculations made with the purpose of comparing the behaviour of the river in flood if basin irrigation is to be replaced by perennial irrigation.

Tables IX. and X. give the dates of the minimum and maximum gauges at Assuân. The minimum gauge was $-\cdot71$ metres on the 23rd June, 1878, and the maximum 9·15 on the 1st October of the same year.

Table XI. gives the amount of water which reaches the sea per month in an average year. The mean discharge is 2060 cubic metres per second, or 65,000,000,000 cubic metres per annum.

Table XII. gives the tons of solid matter carried to the sea in an average year. The total quantity works out to 36,600,000 tons.

Tables XIII. and XIV. give the distances of the principal places on the Nile between Cairo and Assuân, and on the two branches of the Nile measured on the summer track or deep channel.

Table XV. gives the gauges of the Nile at Assuân on the 15th and 30th of each month for all the years from 1871 to 1898.

Now that the Soudan is re-conquered, it will not be long before Nilometres are erected at Lado, Fashoda, Khartoum, Berber, Assuân, Assiout and Cairo, with their zeros corresponding to mean low-water levels. By the aid of these gauges and others on the Saubat, the White and Blue Niles at Khartoum, and the Atbara, placed well above the effects of any backwater, it will be possible to predict the behaviour of the flood in Egypt in October, and the volume of the summer supply in December. Both to the engineers responsible for the regulation of the basins at the time of discharge, and to the agricultural community in deciding on the areas to put under sugar-cane, cotton and rice, this information will be of the greatest practical value. In making these calculations and determining these forecasts, I am justified in hoping that these tables will be of material use.

TABLE I.

MEAN LOW-WATER LEVEL OF THE NILE.

Distance from Assuân along Centre Line of Flood	Name of Locality	R.L. according to Reservoir Levels	R.L. according to Inspectors of Irrigation	Distance from Assuân along Summer Channel
		metres	metres	kilometres
0	Assuân	85·0	85·0	0
70	Gebel Silsila	79·3	79·4	72
106	Edfu	76·7	77·0	..
157	Esna	73·1	72·6	..
194	Armant	70·1	69·6	..
213	Luxor	69·0	68·5	..
272	Kena	65·3	64·8	..
320	Kasr-es-Saad	61·7	61·2	330
328	Heu	61·2	60·7	..
333	Naga Hamadi	61·0	60·5	..
365	Abu Shusha	58·6	58·1	..
373	Balyana	58·3	57·8	..
390	Girga	56·9	56·5	..
429	Sohâg	53·8	53·2	..
470	Khazindaria	49·9	49·4	489
505	Aboutig Escape	47·7	47·1	..
530	Assiout *	45·55	45·05	552
598	Derut Escape	39·1	38·5	..
627	Roda	36·3	35·7	..
666	Minia	32·6	32·0	..
710	Beni Mazâr	28·9	..	748
..	Beni-Suêf	22·1	21·8	..
800	Ashmant	20·5	20·2	842
..	Kushesha Escape	18·9	18·6	..
..	El-Ayàt	15·8	15·5	..
898	Cairo gauge	12·25	12·25	..
900	Cairo	12·0	12·1	948
923	The Barrage	11·0	11·0	973

The mean low-water level at Wady Halfa is R.L. 117·89 metres.

* Below Ibrahimia Canal Head.

TABLE II.

DISCHARGE TABLE OF THE ASSUÂN GAUGE, WHICH MAY BE USED APPROXIMATELY * FOR ANY GAUGE ON THE NILE NORTH OF ASSUÂN WITH ITS ZERO AT MEAN LOW-WATER LEVEL.

Gauge	Discharge	Gauge	Discharge	Gauge	Discharge	Gauge	Discharge
− 1·0	150	2·0	1390	5·0	4350	8·0	9,800
− ·9	170	·1	1460	·1	4500	·1	10,050
− ·8	190	·2	1530	·2	4650	·2	10,300
− ·7	210	·3	1580	·3	4800	·3	10,600
− ·6	230	·4	1650	·4	4950	·4	10,900
− ·5	260	·5	1720	·5	5100	·5	11,200
− ·4	290	·6	1800	·6	5250	·6	11,500
− ·3	320	·7	1880	·7	5400	·7	11,800
− ·2	350	·8	1960	·8	5550	·8	12,100
− ·1	380	·9	2050	·9	5700	·9	12,500
0·0	410	3·0	2130	6·0	5850	9·0	12,800
·1	450	·1	2210	·1	6000	·1	13,200
·2	490	·2	2300	·2	6150	..	..
·3	530	·3	2400	·3	6300	..	..
·4	570	·4	2500	·4	6450	..	..
·5	610	·5	2600	·5	6600	..	..
·6	650	·6	2700	·6	6800	..	..
·7	690	·7	2800	·7	7000	..	..
·8	730	·8	2900	·8	7200	..	..
·9	780	·9	3000	·9	7400	..	..
1·0	830	4·0	3100	7·0	7600	..	..
·1	880	·1	3200	·1	7800	..	..
·2	930	·2	3300	·2	8000	..	..
·3	980	·3	3400	·3	8200	..	..
·4	1030	·4	3500	·4	8400	..	..
·5	1080	·5	3600	·5	8600	..	..
·6	1140	·6	3750	·6	8800	..	..
·7	1200	·7	3900	·7	9050	..	..
·8	1260	·8	4050	·8	9300	..	..
·9	1320	·9	4200	·9	9550	..	..

* The gauges are in metres and are referred to mean low-water level as zero. The discharges are in cubic metres per second. The zero at Assuân is R.L. 85·00, and at Cairo R.L. 12·25.

See the reference to this table on page 42.

TABLE III.—FIVE DAILY GAUGES AND DISCHARGES AT ASSUÂN AND CAIRO FOR THE MINIMUM AND MAXIMUM YEARS, AND THE MEAN OF TWENTY YEARS.

Date	Minimum Year, 1877–78				Maximum Year, 1878–79				Mean of 20 Years			
	Assuân		Cairo		Assuân		Cairo.		Assuân		Cairo	
	Gauge	Dis-charge	Gauge	Dis-charge	Gauge	Dis-charge	Gauge	Dis-charge	Gauge	Dis-charge	Gauge	Dis-charge
June 5	·2	490	·7	490	−·7	210	0	180	·1	450	·9	390
10	·4	570	·7	450	−·7	210	0	180	·2	490	·9	390
15	·8	730	·7	490	−·7	210	0	170	·4	570	·9	380
20	1·0	830	·8	530	−·6	230	−·2	170	·5	610	·9	400
25	1·0	830	1·0	610	−·3	320	−·2	160	·7	690	1·0	420
30	1·4	880	1·3	780	−·6	650	−·2	160	1·1	880	1·1	480
July 5	1·8	1260	1·2	780	·9	780	−·2	170	1·4	1030	1·1	550
10	2·1	1460	1·2	830	1·1	880	·4	300	1·8	1260	1·3	700
15	3·2	2300	1·4	1000	1·4	1030	·8	500	2·3	1580	1·5	850
20	3·2	2300	1·6	1200	2·5	1720	1·0	700	2·9	2050	1·8	1000
25	3·7	2800	2·4	1600	3·8	2900	1·4	950	3·7	2800	2·2	1200
31	4·7	4050	2·8	2000	5·2	4800	2·6	1880	5·0	4500	2·9	1800
Aug. 5	4·8	4200	3·6	2700	5·6	5400	4·1	3200	5·7	5550	4·1	3200
10	5·4	5100	4·0	3100	6·3	6450	4·9	4200	6·6	7000	4·9	4200
15	5·8	5700	4·7	3900	7·2	8200	5·4	5100	7·0	7800	5·7	5550
20	6·4	6450	4·6	3750	7·5	8600	6·0	6000	7·3	8400	5·9	5850
25	6·1	5850	5·3	4800	8·1	10050	6·3	6450	7·6	9050	6·2	6300
31	6·2	6000	5·3	4800	7·6	8800	6·6	6800	7·8	9550	6·4	6600
Sept. 5	6·3	6150	5·2	4500	8·1	10300	6·5	6600	7·9	9800	6·5	6800
10	6·1	5850	5·3	4650	8·5	11500	6·8	7400	7·9	9800	6·7	7000
15	6·0	5700	5·2	4500	8·9	12800	7·2	8200	7·9	9800	6·8	7200
20	6·0	5700	5·2	4500	8·9	12500	7·6	9050	7·7	8800	6·9	7400
25	6·3	6150	5·1	4350	9·0	12800	7·9	9800	7·6	8600	7·0	7600
30	6·1	5850	5·3	4650	9·1	**13200**	8·2	10600	7·4	8200	7·0	7400
Oct. 5	5·6	5100	5·2	4500	8·9	12100	8·4	11200	7·0	7400	6·9	7200
10	5·2	4500	5·0	4250	8·5	10900	8·7	11900	6·7	6800	6·9	7200
15	4·9	4200	4·9	4200	7·9	9300	8·3	10300	6·3	6150	6·8	7000
20	4·6	3750	4·6	3750	7·6	8600	8·1	10050	6·0	5700	6·8	7000
25	4·5	3600	4·4	3500	7·4	8200	7·9	9300	5·7	5250	6·7	6800
31	4·0	3100	4·2	3300	6·8	7000	7·7	8800	5·2	4650	6·2	6000
Nov. 5	3·7	2800	3·9	3000	6·3	6150	7·5	8400	4·8	4050	5·6	5100
10	3·6	2700	3·6	2700	6·9	5550	7·4	8200	4·5	3600	5·1	4350
15	3·4	2500	3·7	2800	5·5	4950	6·9	7200	4·2	3300	4·7	3900
20	3·2	2300	3·7	2700	5·2	4500	6·2	6000	4·0	3100	4·3	3300
25	2·9	2050	3·5	2300	4·9	4200	5·5	4950	3·8	2900	4·0	3000
30	2·7	1880	3·1	2000	4·7	3900	5·5	4950	3·6	2700	3·8	2800

TABLE III.—*continued.*

Date	Minimum Year, 1877–78				Maximum Year, 1878–79				Mean of 20 Years			
	Assuân		Cairo		Assuân		Cairo		Assuân		Cairo	
	Gauge	Discharge	Gauge	Discharge	Gauge	Discharge	Gauge	Discharge	Gauge	Discharge	Gauge	Discharge
Dec. 5	2·5	1720	2·9	1720	4·5	3600	4·9	4200	3·4	2500	3·6	2600
10	2·4	1650	2·7	1650	4·4	3500	4·7	3900	3·2	2300	3·4	2400
15	2·2	1530	2·6	1530	4·2	3300	4·5	3600	3·1	2210	3·3	2300
20	2·1	1460	2·5	1460	4·1	3200	4·4	3500	3·0	2130	3·2	2210
25	2·0	1390	2·4	1390	3·9	3000	4·2	3300	2·9	2050	3·0	2130
31	2·0	1390	2·3	1390	3·8	2900	4·0	3100	2·7	1880	2·9	1960
Jan. 5	1·9	1320	2·2	1320	3·6	2700	3·7	2800	2·6	1880	2·8	1880
10	1·8	1260	2·1	1260	3·5	2600	3·6	2700	2·5	1720	2·7	1720
15	1·6	1140	2·2	1140	3·4	2500	3·5	2600	2·3	1580	2·6	1580
20	1·5	1080	1·9	1080	3·3	2400	3·4	2500	2·2	1530	2·5	1530
25	1·4	1030	1·8	1030	3·2	2300	3·3	2400	2·1	1460	2·4	1460
30	1·2	930	1·7	930	3·1	2210	3·2	2300	2·0	1390	2·3	1390
Feb. 5	1·1	880	1·6	880	3·1	2210	3·2	2210	1·9	1320	2·2	1320
10	·9	780	1·5	780	3·0	2130	3·0	2130	1·7	1200	2·2	1200
15	·8	730	1·3	730	2·9	2050	2·9	2050	1·6	1140	2·1	1140
20	·7	690	1·2	690	2·8	1960	2·9	1960	1·5	1080	2·0	1080
25	·5	610	1·1	610	2·8	1960	2·8	1960	1·4	1030	1·9	1030
28	·5	610	1·1	610	2·7	1880	2·8	1880	1·3	980	1·9	980
Mar. 5	·3	530	1·0	530	2·7	1880	2·7	1880	1·2	930	1·8	930
10	·2	490	·9	490	2·7	1880	2·7	1880	1·1	880	1·8	880
15	·2	490	·9	490	2·6	1800	2·6	1800	1·0	830	1·7	830
20	·1	450	1·0	450	2·6	1800	2·6	1800	·9	780	1·6	780
25	·0	410	·8	410	3·5	1720	2·5	1720	·8	730	1·6	730
30	—·1	380	·8	380	2·5	1720	2·5	1720	·6	650	1·5	650
Apr. 5	—·1	380	·6	380	2·4	1650	2·5	1650	·5	610	1·5	610
10	—·2	350	·6	350	2·3	1580	2·5	1580	·4	570	1·4	570
15	—·3	320	·5	320	2·2	1530	2·5	1530	·4	570	1·3	570
20	—·3	320	·5	320	2·2	1530	2·4	1530	·3	530	1·3	530
25	—·4	290	·4	290	2·3	1580	2·3	1530	·3	530	1·2	530
30	—·4	290	·3	290	2·2	1530	2·3	1530	·2	490	1·2	490
May 5	—·5	260	·3	260	2·2	1530	2·2	1530	·2	490	1·1	490
10	—·5	260	·2	250	2·0	1390	2·2	1390	·1	450	1·1	450
15	—·5	260	·2	230	2·0	1390	2·2	1390	·1	450	1·1	450
20	—·6	230	·2	220	1·9	1320	2·1	1320	0·0	410	1·1	410
25	—·6	230	·1	200	2·0	1390	2·1	1320	0·0	410	1·0	410
31	—·6	230	·0	190	2·2	1530	2·0	1320	·1	450	1·0	410

Gauges in metres, and discharges in cubic metres per second. The zero at Assuân is R.L. 85·00 metres, and at Cairo R.L. 12·25 metres.

TABLE IV.—MEAN MONTHLY GAUGES AND DISCHARGES AT ASSUÂN AND CAIRO FOR THE MAXIMUM AND MINIMUM YEARS, AND THE MEAN OF TWENTY YEARS.

Month	Minimum Year, 1877–78				Maximum Year, 1878–79				Mean of 20 Years			
	Assuân		Cairo		Assuân		Cairo		Assuân		Cairo	
	Gauge	Discharge	Gauge	Discharge	Gauge	Discharge	Gauge	Discharge	Gauge	Discharge	Gauge	Discharge
June .	·8	720	·4	560	−·4	300	−·9	170	·5	600	0·0	410
July .	3·3	2360	1·4	1030	2·9	2020	·8	750	3·1	2200	1·4	1010
Aug. .	5·8	5550	4·6	3840	7·1	7910	5·6	5290	7·1	7900	5·6	5280
Sept. .	6·1	5900	5·1	4520	8·8	12180	7·5	8600	7·7	9170	6·8	7200
Oct. .	4·8	4040	4·7	3910	7·8	9350	8·2	10250	6·1	5990	6·6	6860
Nov. .	3·3	2370	3·4	2550	5·4	4870	6·5	6610	4·2	3270	4·6	3740
Dec. .	2·2	1520	2·2	1520	4·2	3250	4·5	3600	3·0	2180	3·1	2260
Jan. .	1·6	1120	1·7	1220	3·3	2450	3·4	2550	2·3	1590	2·3	1590
Feb. .	·7	710	·8	710	2·9	2030	2·9	2030	1·6	1120	1·6	1120
Mar. .	·1	450	·1	450	2·6	1800	2·6	1800	·9	800	·9	800
April.	−·3	320	−·3	320	2·2	1560	2·2	1560	·3	550	·3	550
May .	−·6	240	−·7	220	2·1	1420	2·0	1370	·1	440	·1	430
Year .	3·0	2000	2·5	1730	4·8	4090	4·6	3710	3·9	2990	3·5	2610
Difference between Assuân and Cairo	370					380				370		

Gauges in metres, and referred to mean low-water level as zero. The discharges are in cubic metres per second. Zero at Assuân is R.L. 85·00, and at Cairo R.L. 12·25.

TABLE V.—SLOPE OF WATER SURFACE IN THE NILE.

From	To	Distance in Kilometres down the Centre Line of the Flood	Distance in Kilometres down the Summer Channel	Slope in Flood	Slope in Summer
Assuân . .	Silsila . .	70	72	$\frac{1}{11,500}$	$\frac{1}{12,600}$
Silsila . .	Kasr-es-Saad .	250	258	$\frac{1}{14,800}$	$\frac{1}{14,800}$
Kasr-es-Saad .	Khazindaria .	150	159	$\frac{1}{12,300}$	$\frac{1}{13,400}$
Khazindaria .	Assiout . .	60	63	$\frac{1}{11,800}$	$\frac{1}{14,500}$

TABLE V.—*continued.*

From	To	Distance in kilometres down the centre line of the flood	Distance in kilometres down the summer channel	Slope in flood	Slope in summer
Assiout . .	Beni-Mazâr .	180	196	$\frac{1}{11,000}$	$\frac{1}{11,800}$
Beni Mazâr .	Ashmant . .	90	94	$\frac{1}{11,000}$	$\frac{1}{11,400}$
Ashmant . .	Cairo . .	100	106	$\frac{1}{11,600}$	$\frac{1}{12,300}$
Cairo. . .	Barrage . .	23	25	$\frac{1}{10,800}$	$\frac{1}{20,000}$
Assuân . .	Cairo . .	900	948	$\frac{1}{12,200}$	$\frac{1}{13,000}$

TABLE VI.

AREAS OF CROSS SECTIONS OF THE NILE, FROM ASSUÂN TO CAIRO.

Locality	Length in kilometres	Mean area in square metres					
		Below zero	Below 6 metres	Below 7 metres	Below 8 metres	Below 8·5 metres	Below 9 metres
Assuân to Assiout . .	528	920	4760	5680	6690	7310	8080
Assiout to Koshesha . .	289	870	5080	6100	7550	8510	9520
Koshesha to Cairo . .	81	1030	5360	6380	7810	8640	9490
Assuân to Cairo . .	898	910	4930	5890	7080	7830	8690

TABLE VII.—CUBIC CONTENTS OF THE TROUGH OF THE NILE IN MILLIONS OF CUBIC METRES.

Locality	Length in kilometres	Contents in millions of cubic metres						Contents in millions of cubic metres					
		Below zero	From zero to 6·0	From 6·0 to 7·0	7·0 to 8·0	8·0 to 8·5	8·5 to 9·0	Below zero	Below 6·0	Below 7·0	Below 8·0	Below 8·5	Below 9·0
Assuân to Assiout	528	487	2030	484	534	327	405	487	2517	3001	3535	3862	4267
Assiout to Kushesha	289	254	1217	295	420	278	291	254	1471	1766	2186	2464	2755
Kushesha to Cairo	81	84	351	83	115	68	69	84	435	518	633	701	770
Assuân to Cairo	898	825	3598	862	1069	673	765	825	4423	5285	6354	7027	7792

TABLE VIII.—WIDTHS OF WATER SURFACE FROM ASSUÂN TO CAIRO.

From	To	Mean width of water surface					
		0	6·0	7·0	8·0	8 5	9·0
Assuân	Assiout	370	880	940	1140	1410	1630
Assiout	Kushesha	460	980	1290	1710	1860	1880
Kushesha	Cairo.	450	960	1100	1570	1700	1700
Assuân	Cairo.	430	940	1110	1470	1660	1740
Area of water surface in millions of square metres.							
Assuân	Assiout	200	470	500	600	740	860
Assiout	Cairo	130	280	370	490	540	540
Assuân	Cairo	400	840	1000	1320	1490	1560
Evaporation (at 8 millimes per day) in cubic metres per second.							
Assuân	Assiout	20	47	50	60	74	86
Assiout	Cairo	13	28	37	49	54	54
Assuân	Cairo	40	84	100	132	149	156

TABLE IX.—DATES AND HEIGHTS OF THE REAL MINIMUM AT THE ASSUÂN GAUGE.

Year	Date	Minimum gauge of the year in metres	
1873	5th June	− ·37	
1874	30th May	− ·64	
1875	23rd May	− ·17	
1876	15th June	+ ·13	
1877	27th May	+ ·10	
1878	23rd June	− ·71	Worst low supply.
1879	23rd May	+ 1·88	Best low supply.
1880	9th June	+ ·82	
1881	14th May	+ ·00	
1882	23rd June	− ·55	
1883	22nd June	+ ·04	
1884	27th May	+ ·37	
1885	21st June	− ·44	
1886	3rd June	− ·06	
1887	8th May	− ·03	
1888	8th June	− ·08	
1889	24th June	− ·60	
1890	8th June	− ·60	
1891	19th May	− ·21	
1892	18th June	− ·64	
1893	18th June	+ ·35	
1894	16th June	+ ·06	
1895	23rd June	+ ·78	
1896	13th June	+ ·49	
1897	31st May	+ ·62	
1898	23rd June	− ·25	

Zero at Assuân is R.L. 85·00.

TABLE X.—DATES AND HEIGHTS OF THE MAXIMUM FLOOD AT ASSUÂN.

Year	Date	Gauge, metres
1873	1st September	7·66
1874	6th September	8·97
1875	11th September	8·36
1876	7th September	8·68
1877	20th August	6·40
1878	1st October	9·15
1879	13th September	8·59
1880	4th September	7·82
1881	4th September	8·14
1882	28th August	8·00—22nd September 7·60
1883	17th September	8·18
1884	1st September	7·73

TABLE X.—*continued.*

		Gauge, metres
1885	28th August	8·05—10th September 8·00
1886	22nd September	8·04
1887	1st September	8·81
1888	24th August	7·08
1889	2nd September	8·36
1890	2nd September	8·72
1891	4th September	7·84—27th September 7·84
1892	20th September	8·88
1893	14th September	7·75
1894	18th September	8·61
1895	10th September	8·68
1896	3rd September	8·63
1897	1st September	7·80
1898	29th August	8·63

Zero at Assuân is R.L. 85·00.

TABLE XI.—AMOUNT OF WATER WHICH REACHES THE SEA IN AN AVERAGE YEAR.

From Table II. the mean discharge at Cairo = 2610 cubic metres per second.

The Delta Canals absorb for the irrigation of Lower Egypt:—

	cubic metres per second
January	300
February	300
March	300
April	300
May	350
June	400
July	500
August	1000
September	1200
October	1200
November	500
December	300
Mean for the year	550

Therefore the mean discharge to the sea = 2610 − 550 = 2060 cubic metres per second; or 65,000,000,000 cubic metres per annum.

As the average rainfall in the Nile basin has been found to be 2,282,000,000,000, the water which reaches the sea = $\frac{1}{35}$ of the rainfall.

TABLE XII.—TONS OF SOLID MATTER CARRIED TO THE SEA IN AN AVERAGE YEAR.

—	Discharge of the Nile at Cairo, cubic metres per second	Discharge of the Delta canals, cubic metres per second	Discharge entering the sea, cubic metres per second
June	410	410	0
July	1010	500	510
August	5280	1000	4280
September	7200	1200	6000
October	6860	1200	5660
November	3740	500	3240
December	2260	300	1960
January	1590	300	1290
February	1120	300	820
March	800	300	500
April	550	300	250
May	430	350	80

SOLIDS CARRIED IN SUSPENSION.

				cubic metres per second
June	0	×	$\frac{6 \cdot 9}{100 \cdot 000}$	= 0·000
July	510	×	$\frac{17 \cdot 8}{100 \cdot 000}$	= 0·098
August	4280	×	$\frac{149 \cdot 2}{100 \cdot 000}$	= 6·386
September	6000	×	$\frac{54 \cdot 3}{100 \cdot 000}$	= 3·258
October	5660	×	$\frac{37 \cdot 8}{100 \cdot 000}$	= 2·139
November	3240	×	$\frac{34 \cdot 4}{100 \cdot 000}$	= 1·114
December	1960	×	$\frac{28 \cdot 9}{100 \cdot 000}$	= ·566
January	1290	×	$\frac{16 \cdot 7}{100 \cdot 000}$	= ·205
February	820	×	$\frac{12 \cdot 6}{100 \cdot 000}$	= ·103
March	500	×	$\frac{5 \cdot 3}{100 \cdot 000}$	= ·026
April	250	×	$\frac{6 \cdot 6}{100 \cdot 000}$	= ·016
May	80	×	$\frac{4 \cdot 8}{100 \cdot 000}$	= ·004
Mean				1·1596

Total quantity of solids carried to the sea in one year, 365 × 1·1596 × 86,400 = 36,569,000 cubic metres; or, say, 36,600,000 tons.

TABLE XIII.

DISTANCES FROM BARRAGE TO ASSUÂN, CAIRO TO ASSUÂN AND BACK, IN KILOMETRES, MEASURED ON THE STEAMER TRACK OR DEEP CHANNEL. UPPER EGYPT.

Name of place	Distance from Barrage	Distance from Cairo	Distance from Assuân	Name of place	Distance from Barrage	Distance from Cairo	Distance from Assuân
Barrage	0	20	968	Khizindârîyah and Tahta	482	459	486
Qasr en Nil Bri.	23	0	945				
Rôdah gauge	27	4	941	Sûhâg	520	497	448
Hawâmdîyah F.	41	18	927	Sahagîyah Canal	521	498	447
Badrishên	46	23	922	Akhmîn	528	505	440
Kafr er Rifâi	61	38	907	Menshîyáh	543	520	425
Aiyât	73	50	895	Girgâ	561½	538½	406½
Kafr Ammâr	87½	64½	880½	Baliyanâ	578½	555½	389½
Riggah	96¾	73¾	871¼	Abu Hammâdî	623	600	345
Wâstah	108	85	860	Hew	627	604	341
Ashmant	125	102	843	Qasr es Sayyâd	637½	614½	330½
Beni-Suef	143	120	825	Fâw	654	631	314
Bibâ	163	140	805	Samtah & Dishnâ	665	642	303
Feshn	176	153	792	Qinâ (Kena)	685	662	283
Maghâghah	199	176	769	Ballâs	701	678	267
Beni Mazâr	216	193	752	Qift	704	681	264
Matâî Factory	230	207	738	Qôs	714	691	254
Samâlût	244	221	724	Naggâdah	716½	693½	251½
Minyà	268	245	700	Qamûlah	735	712	233
Beni Hasan	293½	270½	674½	Luxor	749½	726½	218½
Rôdah	308	285	660	Armant	768	745	200
Tall Amârnah	330	307	638	Matâána F.	798½	775½	169½
Dêrût Escape	340	317	628	Isnâ (Esna)	807½	784½	160½
Nazali Ganûb	352	329	616	El Kâb	840	817	128
Manfalût	377	354	591	Kelh el Gebel	846	823	122
Mangabât	406	383	562	Idfu	859	836	109
Asyût	420	397	548	Rammâdî Canal	885	862	83
Abu Tîg	443	420	525	Gebel Silsilis	898	875	70
Sid fâ	454	431	514	Kom Ombo	925	902	43
Timâ	460	437	508	Assuân	968	945	0

TABLE XIV.

DISTANCES FROM THE BARRAGE TO THE SEA DOWN THE DAMIETTA AND ROSETTA BRANCHES, AND VICE VERSÂ, MEASURED ON THE STEAMER TRACK OR DEEP CHANNEL IN KILOMETRES.

Name of place	Distance from Barrage	Distance from Sea	Name of place	Distance from Barrage	Distance from Sea
DAMIETTA BRANCH			ROSETTA BRANCH		
Birshams	23	213	Ashmún Escape	23	213
Ataf	35	201	Gerés	31	205
Khadarawia Hd.	44	192	Khatatbeh	45	191
Benha	51	185	Baiwash Escape	53	183
Mitbera	62	174	Gizai	63	173
Zifta	88	148	El Kám	78	158
Mansuria Hd.	91½	144½	Tenoub	95	141
Mit Badr	106	130	Nagila	102	134
Samanúd	124	112	Kafr Zyat	119	117
Mansurah	142	94	Kuddaba	140	96
Sherbín	168	68	Shibrakhit	154	82
Rasel Khalig Station	182	54	Desook	168	68
Mit Abu Gálib	194	42	Bahr Saidi	170	66
Faraskúr	203	33	Fuah	181	55
Damietta	221	15	Atfé	184	52
Sea	236	0	Deféna	198	38
			Rosetta	221	15
			Sea	236	0

TABLE XV.—ASSOUÂN GAUGE READINGS.

Dates	1871	1872	1873	1874	1875	1876	1877	1878	1879	1880	1881	1882	1883	1884	1885	1886	1887	1888	1889	1890	1891	1892	1893	1894	1895	1896	1897	1898
Jan. 1	3·43	2·51	3·01	2·06	2·98	2·85	2·62	1·97	3·70	3·39	2·58	2·53	2·54	2·85	2·65	2·19	2·53	2·82	1·59	2·26	2·94	2·78	3·25	2·76	3·34	3·28	3·63	2·33
15	3·14	2·08	2·67	1·57	2·73	2·62	2·26	1·61	3·41	3·14	2·20	2·22	2·29	2·58	2 38	1·86	2·28	2·58	1·25	1·99	2·62	2·42	3·03	2·49	3·07	2·89	3·10	2·13
Feb. 1	2·74	1·45	2·44	0·94	2·40	2·38	1·77	1·21	3·12	2·92	1·79	1·90	2·06	2·33	2·08	1·32	1·90	2·06	0·69	1·56	2·17	1·99	2·78	2·13	2·74	2·62	2·74	1·90
15	2·47	0·98	2·31	0·58	2·04	2·20	1·39	0·80	2·89	2·76	1·52	1·57	1·81	2·13	1·79	0·93	1·50	1·52	0·39	0·98	1·54	1·59	2·62	1·72	2·55	2·40	2·46	1·54
Mar. 1	2·19	0·55	1·99	0·28	1·61	2·02	1·14	0·44	2·74	2·58	1·16	1·05	1·66	1·97	1·30	0·66	1·11	1·16	0·12	0·62	1·07	1·00	2·40	1·16	2·40	2·04	2·15	1·12
15	1·84	0·31	1·41	0·13	1·07	1·75	0·78	0·17	2·60	2·26	1·00	0·67	1·48	1·75	0·82	0·51	0·80	0·82	—·06	0·28	0 62	0·64	2·31	0·76	2·15	1 68	1·90	0·73
Apr. 1	1·21	0·04	0·73	—·12	0·58	1·21	0·46	—·10	2·44	1·79	0·58	0·35	1·05	1·32	0·46	0·33	0·30	0·51	—·21	—·11	0·28	0·26	2·24	0·40	1·86	1·21	1·39	0·44
15	0·76	—·17	0·37	—·32	0·40	0·80	0·31	—·26	2·22	1·54	0·40	0·08	0·67	0·96	0·22	0·10	0·12	0·39	—·33	—·24	0·08	—·06	2·15	0·26	1·48	1·03	1·05	0·19
May 1	0·42	—·10	0·01	—·41	0·19	0·42	0·35	—·41	2·24	1·27	0·19	—·12	0·22	0·85	—·05	0·13	0·01	0·12	—·48	—·44	—·15	—·30	1·48	0·06	1·16	0·82	0·85	0·06
15	0·26	—·26	—·21	—·55	—·03	0·28	0·28	—·50	1·95	1·12	0·01	—·23	0·13	0·62	—·19	0·19	0·28	0·10	—·48	—·51	—·19	—·35	0·87	0·10	1·00	0·67	0 69	—0·05
June 1	0·22	—·21	—·32	—·32	0·10	0·19	0·19	—·66	2·20	0·89	0·19	—·30	0·06	0·69	—·41	—·03	0·42	—·06	—·55	—·51	0·01	—·60	0·60	0·17	1·16	0·55	0·64	—0·21
15	0·01	—·03	1·68	0·71	—·01	0·17	0·91	—·66	2·35	1·03	0·13	—·41	0·15	0·55	—·39	0·35	0·35	0·10	—·51	—·26	1·54	—·48	0·37	0·08	0·85	0·53	0·67	—0·21
July 1	1 07	1·44	2·44	1·50	0·73	2·06	1·30	0·67	2 35	1·41	0·80	0·42	0·78	1·14	1·05	0·80	1·41	0·69	0·24	0·53	1·72	0·28	0·57	·99	1·16	0·89	1·72	0·75
15	2·13	2·01	2·26	2·71	2·13	3·12	3·23	1·44	3·97	3·82	1 79	0·89	2·38	1·86	2·94	1·68	2·80	1·18	1·16	1·95	2·13	1·63	1·36	2·44	2·60	2·31	2·17	1·11
Aug. 1	5·30	5·46	3·75	6·49	5·66	5·68	4·72	5·39	5·66	5·84	4·02	3·43	6·31	3·68	6·65	4·56	5·88	3·70	5·77	5·75	4·80	5·75	5·70	5·17	6·81	5·10	3·39	3·07
15	8·09	7·62	6·72	8·47	7·73	7·08	5·75	7·17	7·66	7·21	6·00	5·73	7·08	6·54	7·24	7·46	8·40	6·27	6·78	7·80	7·03	6·70	6·96	7·71	8·05	6·49	6·70	7·35
Sept. 1	8·11	7·82	7·66	8·70	8·05	8·23	6·18	7·60	7·96	7·62	8·07	7·66	7·89	7·73	7·84	7·14	8·81	6·81	8·36	8·67	7·73	8·36	7·33	8·54	8·54	8·58	7·80	8·39
15	8·14	8·11	7·31	8·74	8·00	8·43	6·02	8·90	8·56	7·26	8·02	7·37	8·02	6·97	7·64	7·91	8·63	6·76	7·95	8·22	7·89	8·77	7·64	8·49	8·34	8·29	7·51	8·19
Oct. 1	7·44	7·64	6·43	8·11	7·78	7·60	6·04	9·15	7·64	7·44	7·28	6·81	7·42	6·54	6·49	7·17	7·55	5·90	7·23	7·59	7·50	8·36	7·21	8·23	6·94	7·46	7·03	7·59
15	6·11	7·21	5·75	7·21	6·90	6·45	4·92	7·91	6·70	6·04	6·25	5·64	6·04	6·02	5·98	5·73	6·36	4·74	6·54	7·23	6·54	7·42	6·96	7·69	6·47	6·56	5·98	6·73
Nov. 1	4·78	5·73	4·38	5·48	5·80	4·83	3·88	6·72	5·48	4·49	5·05	4·99	5·10	5·55	4·51	4·60	5·10	3·43	4·71	6·18	5·79	6·16	5·50	6·11	5·17	5·68	4·56	5·61
15	3·91	5·35	3·50	4·58	4·63	4·24	3·41	5·50	4·58	3·80	4·15	4·67	4·22	4·42	..	3·66	4·29	2·73	3·72	4·92	5·05	4·96	4·47	4·81	4·42	4·83	3·59	5·18
Dec. 1	3·37	4·27	2·94	3·95	3·77	3·50	2·60	4·67	4·06	3·16	2·43	3·79	3·57	3·66	2·96	3·32	3·57	2·22	2·96	3·97	4·02	4·06	3·64	4·15	3·88	5·35	2·98	4·02
15	2·96	3·64	2·53	3·41	3·39	3·03	2·22	4·20	3·70	2·92	2·96	3·03	3·25	3·10	2·62	3·18	3·18	1·92	2·64	3·45	3·32	3·59	3·16	3·75	3·73	4·54	2·62	3·63
31	2·53	3·01	2·11	3·01	2·87	2·65	1·99	3·75	3·41	2·58	2·54	2·58	2·87	2·67	2·24	2·53	2·87	1·63	2·28	2·94	2·78	3·28	2·78	3·36	3·30	3·66	2·33	3·06

CHAPTER III.

BASIN IRRIGATION IN UPPER EGYPT.

PART I.

Basin irrigation before 1889—System of filling and emptying basins—Theoretical quantity of water needed for basins in an ordinary year—Comparison between Assuân and Cairo gauges in flood —Sir Colin Scott-Moncrieff on the remodelling of basin irrigation—Colonel J. C. Ross on the method adopted for remodelling the basins—Difference between the old and new régimes—Regimen of the Nile—Amount of water delivered—Summer irrigation in the basin tracts—Drainage of basins—Maintenance of banks—Maintenance of canals—Maintenance of masonry works—Declaration of a bad or low Nile—Measures to be adopted in a low year—Conclusions drawn from the low flood of 1888—Conclusions drawn from an examination of the rental values of the lands of Upper Egypt—Main factors affecting rents—Flood and summer millets—Muddy and sandy canals—Utilisation of subsoil water—Bahr Yusuf basins—Discharges of the basin canals in 1892 and 1893—Duty of existing basin canals in a mean year, in a minimum, and in a maximum year—Duties of basin canals by systems in a mean year—List of basins—List of basin canals—Dates of openings of basin canals, 1884-1897—Dates of discharges of basins, 1884-1897—Lengths of basin canals, banks, and number of regulating works, &c.

IN the first edition of this work, written in 1888, before the improvement works carried out by Lieut.-Colonel J. C. Ross, C.M.G., were undertaken, I thus described the system of basin irrigation as it then existed :—

"The delta of the Nile, from Assuân to the Mediterranean, having been formed by the gradual deposit of alluvial matter from the Nile in a state of flood, the high land is always on the river bank, and the low land near the desert.* This feature is found not only along the main channel of the river, but also along its branches. Plate IX., which gives cross sections of the valley near Kena and Cairo, shows these features distinctly. This natural deltaic formation has been slightly modified by the artificial construction of dykes running both longitudinally with and transversely across the direction of the stream. These dykes enclose basins which are annually flooded with water during the inundations. The slopes, therefore, are not quite gradual, but in a series of terraces or steps.

"Upper Egypt, with the exception of the Ibrahimia Canal system and the Fayoum, is divided into basins by earthen dykes running transversely to the direction of the river, starting from its bank and reaching the desert. A dyke running parallel with the river, along its bank, encloses the basins

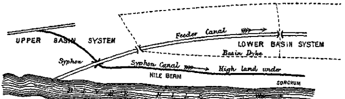
* Roorkee treatise on Civil Engineering.

on the river side, while the desert generally forms the fourth side. Some basins are still further divided by one or more dykes parallel to the direction of the river, in order to divide the low lands near the desert from the higher lands near the river's edge. Large communities have made further subdivisions, surrounded their property by dykes, and made private basins or enclosures which they can irrigate at will, and of which they control the water supply independently of the main basins. Almost all these basins have special canals to lead directly into them the flood waters charged with alluvium. The beds of these canals are almost midway between low Nile and ground level, i.e. about 3 or 4 metres below the level of country, or the same depth below ordinary flood. The canals are consequently dry during winter and summer. Many of the feeder canals have no regulating heads, but only a mass of loose stone at the take-off from the river. The heads of the canals taking from the Nile are annually closed with earthen banks, which are cut about the 10th or 12th August, when the millet crops in the basins have been removed, and the Assuân gauge being ordinarily at 7 metres, the muddy flood water can flow freely into the canals. Each system of basins depends on one or more canals for its irrigation; some of the canals are insignificant, and feed only a few basins; while some, like the Sohagia, discharging 450 cubic metres per second, are veritable rivers, and irrigate a very extended system. As the feeder canal passes each transverse dyke it is provided ordinarily with a masonry regulator, to control the amount of water entering the basins. Each system of basins possesses an escape, which allows the water, after it has deposited its alluvium and stood some forty days on the land, to flow back into the river. Wherever the desert impinges on the river bank there is a break in the system of basins. This happens very frequently on the right bank but seldom on the left, where nearly all the cultivated land lies.

"The filling of the basins begins ordinarily about the 12th August, and in the southernmost basins is completed by the 1st October, when the escapes are opened and the water discharged back into the Nile ordinarily by the 15th October. As one advances northwards the date of discharge, and consequently of emptying of the basins, becomes later, until at the last basin north of the Barrages the escape is ordinarily opened on the 11th November, and the basin dry by the 30th November. When the time of emptying the basins has arrived, if the basins have been completely filled and the Nile has fallen considerably, the escapes are opened and the water discharged. When masonry escapes do not exist the bank is cut; this breach has to be annually repaired before the next flood. If the flood has been a low one, and the basins are not quite full, wherever possible the upper series of basins is drawn on and their water discharged through the lower, thus completing the irrigation. If the Nile is still high when the

time of emptying has come, there is no resource but to let the water stand in the basins till the Nile is low enough. This occurs very seldom indeed. The delay in drying the basins is said to engender worms which destroy the crops, while the delay itself puts off the ripening of the grain into the month of April, when hot winds parch the corn and make the crop a light one. The land near the banks of the Nile is so high that ordinarily the Nile cannot cover it. It is flooded eight or nine times a century, when the Assuân gauge is over 8·50 metres. This land is planted with millets in flood, and irrigated by means of minor canals, known locally as syphon-canals, because they bring their water at a high level from an upper series of basins and pass it under the next feeder canal by a syphon.

"Since the slope of the basin canals is about $\frac{1}{20000}$, while that of the Nile is $\frac{1}{12900}$, and that of the country $\frac{1}{10800}$, it takes $36\frac{1}{2}$ kilometres for such a basin canal to gain 1 metre on the Nile, and $23\frac{1}{2}$ kilometres to gain 1 metre on the country. These syphon or berm canals, which permit of a double crop on the high lands near the Nile (viz. millets during flood,



and wheat, beans, &c., in winter), are dammed up in so many places along their course in order to raise the water surface as much as possible, that the silt deposits are enormous. The yearly clearance of these deposits is a very serious matter.

"On the left bank of the Nile, from Assuân to the Ramádi Canal head (a distance of 83 kilometres), there is but one small basin. From the Ramádi Canal head to a point 20 kilometres north of Kena, where the desert impinges on the Nile for the last time (a distance of 220 kilometres), the basins are irrigated by three systems of canals, which are separated from one another by rocky headlands of desert, but provided with canals traversing these desert headlands. From the last desert bank to Sohag, a distance of 144 kilometres, there are two systems of basins. From Sohag to a point 100 kilometres north of Assiout, a distance of 200 kilometres, the Sohagia Canal feeds the basins. From the tail of the Sohagia Canal to Girza, a distance of 235 kilometres, the Bahr Yusuf, aided by six canals, feeds the basins; while the remaining 100 kilometres to the Barrage are fed by the Girza Canal. From Assiout northwards, on a length of 295 kilo-

metres and an area of 250,000 acres, Ismael Pasha in 1873 took up the land corresponding to the tracts irrigated by the syphon canals and the eastern parts of the basins, dug a deep summer canal, known as the Ibrahimia, and introduced summer irrigation. The Bahr Yusuf, which used to take out of the Nile, had its head transferred to the left bank of this canal, and was thus supplied with summer water for consumption in the Fayoum. Previously to this the Bahr Yusuf used to obtain its summer supply from infiltrations only. The Bahr Yusuf, after following the depression near the desert, finds at Lahoun a gap in the hitherto continuous chain of Libyan hills; it escapes through the Lahoun regulator, on the line of the Lahoun embankment (which does duty here for the Libyan hills), and irrigates the province of the Fayoum.

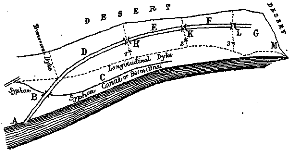
"Plate XIII. gives a plan of Upper Egypt, showing the basins and canals. Since the slope of the country is greater than that of the Nile, it is not difficult to obtain a sufficient velocity in the canals to carry the Nile mud to the furthest parts of the basins in any well-regulated system. There are altogether 141 basins on the left bank in Upper Egypt, covering an area of 1,155,500 acres, while on the right bank there are 71 basins covering an area of 279,500 acres. There are therefore altogether 1,435,000 acres in 212 basins, with a mean area of 8200 acres per basin on the left bank, and 4000 acres per basin on the right bank; or, for the whole of Upper Egypt, a mean area per basin of 6800 acres. Of the balance, 581,500 acres are under summer irrigation on the Ibrahimia canal and in the Fayoum, and 296,800 acres are under flood irrigation on the Nile berms. Two of the largest basins in Upper Egypt are Delgâwi, at the tail of the Sohagia system, and Koshêsha, at the tail of the Bahr Yusuf system; the former contains 50,000 acres, and the latter 75,400 acres. The table on page 23 gives full details of these figures.

"The basin dykes have an average width at top of 6 metres, height of 3½ metres and slope of 1 in 1; a few of the transverse dykes are pitched with stone on their northern slopes, to break the force of the waves when the basins are filled with water. Since the average depth of water is 1·50 metre on very extended areas, and Upper Egypt in flood time is like a great lake in the heart of the dry parched desert, it is common to have sudden severe storms which endanger the banks. The villages within the basins are on artificial mounds, protected with stone; and during flood they are so many small islands, between which communications are kept up by boats or by the dykes.

"The accompanying sketch gives a general plan of an independent system of basins. A is the head of the basin canal; B is the syphon for the syphon canal; C is the high land under millet; D, E, F, G, are basins, of which the tail basin G is nearly always the largest; H, K, L, are regulators; M is the final escape over the rocky desert headland. Each basin

may be assumed to be from 5000 to 15,000 acres in extent, or on an average 10 kilometres long and 4 broad.

"Previous to the rise of the Nile, the basin canal is closed at its head by an earthen dam, which is cut about the 12th August. If the system is a perfect one, there is a regulating head at A, and a regulating escape at M, with regulators in the transverse banks at 1, 2, and 3. This, however, is very rare indeed. By the 12th August the Nile is high enough to enter the basin canal with great velocity, and carry its slime to the furthest basin G, all the regulators being fully open. The regulators are kept open until the lowest basin G is within 30 centimetres of its full supply, when the regulator L is partially closed; and so on up the series, until the first regulator H is reached, when the filling of the first basin D is taken in hand by closing the regulator H. When the basins are empty, there is at first a severe draw at the head of the basin canal, and too great a velocity to allow of silt deposit. As the basins fill up, however, the slopes become less



and less, and eventually become so small that in very many of the canals a heavy silt deposit takes place. If the canal has a discharge insufficient for the series of basins, the closing of the regulator takes place very late, and the velocity not being checked, there is no silt deposit in the canal; when, however, the canal has a sufficient discharge, the closing of the regulators causes heavy silt deposits. If the flood is an average one, the operation of filling the basins is over in forty days; that is, if the filling began on the 12th August it is over by the 22nd September; if the flood is a very high one it may be over by the 1st September; if a low one, by the 1st October. When the upper basin D is full, the canal head is closed by throwing in stone pitching if there is no regulating head; by closing the head regulator, if there is one. This generally takes place about the 22nd September, though it may be over on the 1st September. The evaporation and absorption, meanwhile, which are together about 8 millimetres per day, and, therefore, equal to $\left(\frac{4200 \times 8}{100} = \right) 33{\cdot}6$ cubic metres

per acre per day, considerably reduce the quantity of water inside the basins. While these basins are standing simmering, the Nile is steadily falling, and very frequently the water in the first basin D becomes higher than that in the Nile. In the southern provinces the 1st October is the day to begin discharging the basins. This is a very delicate operation. The situation must first be taken in. In an ordinary year the upper basin D is full of water, the other ones are within 30 centimetres of full supply, the regulators are closed, holding up about 1·50 metre each; and the escape M is closed. Ordinarily the escape M is first opened, and then the regulators L, K, H, so that basin D is discharging more into basin E than E is into F, and basin F is discharging more into basin G than the escape M is; by this means all the basins are filled to their proper height before they are dried. Basin D is the first to be empty, and basin G is the last. As the beds of the basins gradually appear, beginning at the south and moving northwards, because the south end is always higher than the north, the sowing broadcast of the seed on the slime commences. The first basin in Upper Egypt is dry ordinarily by the 5th October, and the last by the 30th November.

"This is the basin system in its simplest aspects in an ordinary, and therefore favourable year. If the flood were always a good one, an independent basin system would always be the best, as the system is self-containing, and at the time of discharge, discharges straight into the Nile, and does not complicate matters lower down. It will be noticed, however, by referring to the sketch, that the system above this one was in communication with it; and if the flood were a bad one, the upper system was capable of sending down enough water to completely fill the basin D and flush all the other ones, and leave not a single acre unirrigated. The system below the one on the sketch is not so favourably situated; no water can pass the rocky desert at M, and, consequently, if the flood is below the average, the upper basins of the next series will not be completely filled, lacking the aid from above. The syphon canal at B, which irrigates the high lands flush, will also be an impossibility, and consequently the lands below these rocky headlands, and below the Sohagia Canal head, where there is no syphon, are always poor and inferior. It is on account of the frequency of low Niles that systems in communication with each other are much to be preferred.

"It often happens that during the filling of the basins, owing to an accident, or the failure of some regulating apparatus, one or more basins get more water into them than their proper allowance, and threaten to burst the transverse banks. This water has to be carefully distributed among the other basins. The relieving of the basins is quite a distinct operation from the final discharging. If one of the transverse banks is breached, which fortunately happens very seldom, the whole series of

transverse banks may have to be breached to prevent inundations; and that means impossibility of good regulation, and heavy repairs afterwards. All these difficulties exist because there is a great lack of masonry regulators in the transverse dykes and a lamentable absence of masonry escapes. If there was a good masonry escape attached to each system of basins, surplus water could easily be disposed of; but since there is no masonry escape, as a rule, the engineers know well that once the final escape is cut there is no closing it again, and consequently have to be very hard put to it indeed ere they cut the final bank before the proper time of discharge. With a good tail escape and ample masonry regulators in the transverse dykes, it would be possible to run the flood water through the basins during the whole flood, and thus gain much additional slime on to the lowest basins, instead of, as at present, bottling up the basins through half the flood, and letting them simmer under a hot tropical sun.

"After passing a point about 20 kilometres to the north of Kena there are no places where the desert impinges on the left bank of the Nile, and the different systems of basins are in communication with each other. These basins are in principle the same as those described above, except that they all tail into one another. The two main points of escape are: Abutîg, south of Assiout, for all the basins of Girga and half those of Assiout; and Abu Kadîga, opposite the Koshêsha basin, for all the basins between the Ibrahimia Canal and the desert. Since the construction of the Ibrahimia summer canal, the basins between the tract irrigated by it and the desert, which depend for their water on the Bahr Yusuf, have never had enough of red muddy water, and many of them can only be filled at the time of discharge, for a few days, with clear water which has left its deposit elsewhere. This means great deterioration of soil. Captain Brown, Inspector of Irrigation, has been able to increase the muddy water supply by supplementary canals, taking direct from the Nile, and discharging through syphons under the Ibrahimia Canal; while Major Ross has left the breach in the Koshêsha basin bank open through the flood, and thus obtained for this extensive tract of land a supply of muddy water direct from the Nile, which has increased the yield of the crops fully 30 per cent. In discharging the water from this long series of basins through the Koshêsha dyke, three factors have to be considered: 1st, all the upper basins shall have been filled to their proper level; 2nd, the Koshêsha basin shall not be drowned out, and have to relieve itself into the next system of basins, and swamp it; and 3rd, the water shall not come down in a quantity and at a time inconvenient to Lower Egypt, which at this stage of the flood lies at the mercy of this basin water. The Nile at the Barrages rose 1·50 metre in thirty-six hours in October 1884, on the rupture of the Koshêsha dyke. Below Koshêsha lies the province of Gizeh, with a self-contained system which works well.

"The problems before the engineers who have charge of basin irrigation are threefold. The first has reference to the fact that as many acres as possible should be irrigated every year so that the land tax might be assured. The second has reference to the times of filling and emptying of the basins so that full advantage might be taken of the Nile flood, and at the same time all the basins emptied and uncovered at a time eminently suited for the sowing of the winter crop. The third problem has for its solution a distribution of the red muddy waters of the Nile flood in such a manner that all the basins and every part of every basin, shall have, as far as possible, its fair share of the rich deposit of mud. The latter is possibly the most difficult of the three, as there is always a tendency for the heavy sand to drop first, and then the rich mud, and finally the very finest particles of mud. If the distribution is bad, as it is on the Bahr Yusuf basins, some basins receive little but sand, others have far more than their share of rich mud, and the greater part have nothing but the finest particles of mud with a large proportion of salts; especially is this the case where white water has stood for any length of time without any perceptible flow. Good basins like those of Girga have the least of these defects.

"One cannot study the principles of basin irrigation without admiring the skill and order of the whole operation. However much fault may be found with the unskilful treatment of the new summer irrigation in Lower Egypt, the basin irrigation of Upper Egypt, gradually developed through 5000 years, commands sincere admiration.

"It will readily be understood that since the country has a slope of about $\frac{1}{10800}$, the mean depth of water needed to cover a large basin some 15 or 20 kilometres long is much greater than that needed for a small basin some 5 kilometres long. To completely fill a basin of—

acres.		metres.	cubic metres per acre.
From 35,000 to 45,000	there is needed a mean depth of	$\frac{2·5 + 1·0}{2} = 1·75$;	or 7350
" 25,000 " 35,000		$\frac{2·0 + 1·0}{2} = 1·50$;	or 6300
" 10,000 " 25,000		$\frac{1·5 + 1·0}{2} = 1·25$;	or 5250
" 5,000 " 10,000		1·0 =	or 4200
Less than 5,000 acres		·75 =	or 3150

"For a healthy system the quantity should be supplied in forty days, and since 9000 acres represent an average sized basin in Upper Egypt, the mean discharge of a feeder canal should be $\frac{4200}{40} = 105$ cubic metres

per acre per day, or 1 cubic metre per second per 800 acres. The basins are never filled to their full depth by the feeder canals; they are filled to within some 30 centimetres of full supply, and then the canal heads are shut. This, however, does not affect the supply needed from the canals, as the loss by evaporation and absorption is 8 millimetres daily, or 32 centimetres in forty days; the canals, therefore, should supply $\frac{4200}{40}$ = 105 cubic metres per acre per day; and the escapes discharge $4200 - \frac{32 \times 4200}{10}$ = 2856 cubic metres per acre, or 143 cubic metres per acre per day, or 1 cubic metre per second per 600 acres for twenty days. After the canal heads have been shut, the full supplies into the basins are obtained by manipulation between the basins themselves. The above quantities will hold good for even the large basins, since most of them have reserved for millets large areas which are separated from the rest of the basins by subordinate dykes, and are only filled at the time of the discharge after the millet crop is off the ground. In very many of the larger basins, so late is the full supply in coming, that all the higher lying parts of the basins are sown with millet in August, and reaped in October, before the final filling takes place. These fields are not protected by banks.

"By examining the tables of basins, which give the times of discharge of each series, it will be seen that in an average year the quantities of water discharged from the basins of Upper Egypt are as follows—

	acres			cubic metres per day	cubic metres per second
Kena and Esna,	300,000	× 143,	Oct. 1 to Oct. 20 =	42,900,000	or 500
Girga and Assiout,	500,000	× 143,	Oct. 5 to Oct. 25 =	71,500,000	or 820
Bahr Yusuf series,	500,000	× 143,	Oct. 15 to Nov. 5 =	71,500,000	or 820
Geeza and Rikka,	100,000	× 143,	Oct. 10 to Nov. 5 =	14,300,000	or 170
	1,400,000				

"The rest is discharged into the Rosetta branch of the Nile. The supplies to be expected in Lower Egypt in an ordinary year, taking five days from Kena, four days from Assiout, and one day from Koshêsha, are therefore:—

	cubic metres per second
October 5th	450
" 10th	1200
" 16th	2300
" 20th	2300
" 26th	1800
" 31st	900
November 6th	120

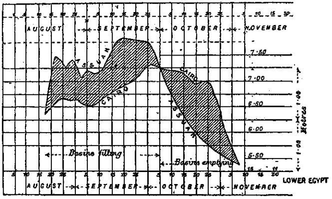
"The discharge of the Nile at Cairo when the guage is—

3 metres is	2130	cubic metres per day
4 "	3100	" "
5 "	4350	" "
6 "	5850	" "
7 "	7600	" "
8 "	9800	" "

"When it rises

From 4 to 5 metres	the increase is	1250	cubic metres per day
" 5 to 6 "	"	1500	"
" 6 to 7 "	"	1750	"
" 7 to 8 "	"	2000	"

"An extra discharge of 2300 cubic metres per second means, therefore, in an ordinary October when the gauges are between 6 and 7 metres, a rise 1·20 metres. By referring to the following diagram of the Assuân



and Cairo gauges for 1886, it will be seen that this rise does actually take place in October. This diagram has been prepared by making the Assuân gauge of the 1st October correspond with the Cairo gauge of the 6th October, because at that date the filling of the basins is practically completed, and the discharge not yet begun.

"The gauges are also made to correspond on the 17th August and 8th November (Lower Egypt dates), and the Assuân curve *very* slightly altered between October 22nd and November 8th to allow for the Assuân water reaching Cairo in five-and-a-half days during full flood, and in eight days at the early and late stages.

"In the table of canals in Upper Egypt, it will be noticed that the level to which the bed of each canal is cleared has been referred to the Assuân or Cairo gauge, according as it is upstream or downstream of the Koshêsha basin. This is a very practical method of understanding the canals, without the aid of levels. The Nile is so uniform in its flow during the period of filling the basins, that if it had reached a certain height at the time of filling, when the Assuân gauge was 7 metres, say in 1881, it will be at the same height for the same gauge in 1888. By this means the canals are cleared so as to allow them to take in water at a certain stage of the river. Formerly, they used to be cleared to a very low gauge and given slopes of $\frac{1}{50000}$, but now they are cleared to the gauges recorded in the table, and given slopes of $\frac{1}{20000}$ and $\frac{1}{33333}$ in very exceptional cases in the Kena province. By this means the silt clearance has been much reduced, without any appreciable loss of water, since the Nile rises very quickly at the beginning of the flood after it has once passed 3·50 metres at Assuân. For the Geeza province the levels are referred to the Cairo gauge as it is close at hand, and much affected by the escape water from the upper basins. Advantage has been taken of the long continuance of the flood in this province, compared to the stay in the upper provinces, to have smaller canals for filling the basins, since a good supply can always be counted on for 60 days, instead of only 40 days. Owing to its lying so far north also, this delay is not prejudicial to the crops, as it would be in Esna and Kena. The readiness with which an intelligent Egyptian engineer refers every basin and canal to the inclined plane of the Nile flood starting from the Assuân gauge, is surprising to one accustomed to refer all heights to a horizontal base, such as mean sea. In the long Nile valley, however, to the south of Cairo, there is great wisdom in adhering to the inclined plane, if for nothing else, as an insurance against mistakes in levels."

Since the above was written a great deal of literature has appeared on basin irrigation, and great improvements have been made in the irrigation itself. During 1886 and 1887, Colonel Ross had been carefully studying the basin systems of Egypt and preparing a scheme for remedying the more patent wants, when the low flood of 1888, followed by a loss of revenue of 300,000*l.*, induced the Egyptian Government to borrow 800,000*l.* and devote it to the execution of works for the protection of the country from drought, known locally as "sharâki."

In a note on the prevention of "sharâki" or drought in Egypt, written by Sir Colin Scott-Moncreiff on the 16th December, 1888, and published by the Egyptian Government in 1889, the principle on which the works were to be carried out is very clearly stated. From it I make the following selection.

"On the 10th November, 1888, the Council of Ministers invited the Ministry of Public Works to take into serious consideration the large area of land left year by year uncultivated for want of irrigation during the Nile flood, and the very serious loss resulting to the revenue and to the country.

It appears that after the flood of 1877 an area of 947,471 acres remained uncultivated, causing a loss of revenue of L.E. 1,111,880. In the following years up to 1887 there has been on a yearly average 45,126 acres drought, with a loss of L.E. 37,718. The returns for 1888 are not yet known, but the estimated area is 260,000 acres, with a loss of L.E. 300,000. These figures justify a close inquiry into the subject, and a large outlay to obviate the yearly loss.

In the following note I can be little more than the exponent of the views of Lieutenant-Colonel J. C. Ross, C.M.G., who has for some years past made the closest study of the irrigation system of Upper Egypt, and whose unrivalled knowledge of the subject imparts the greatest confidence in his results.

The records of this Ministry give the height to which the Nile has risen annually at Cairo throughout the last 150 years.

During these years the following have been the lowest Nile floods:—

Years	Gauge at Cairo metres	Gauge at Assouan metres
1782	5·75	?
1783	5·70	?
1784	5·80	?
1832	5·90	?
1877	5·40	6·40
1888	5·80	7·10

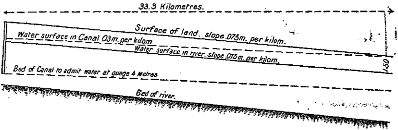
There is no record of the Nile gauge at Assouan earlier than 1869, nor of the extent of drought earlier than 1877, when the failure far exceeded any year of which we have record. It is particularly to be noticed that during three succeeding years the flood failed to attain the height of 1888. We have no right then to count on a better flood during 1889 than the last.

In years such as 1888 the water surface never overflows the valley. To inundate it, therefore, canals having bed slopes less than that of the river have been constructed, along which the water flows, until its surface is higher than that of the fields. Supposing the slope of the river to be 7½ centimetres, and of the canal 3 centimetres per kilometre, it is evident that at the end of a kilometre the water surface in the latter will be 4½ centimetres higher than in the former, and if the surface of the land is 90 centimetres higher than the water surface of the river, the water in the canal will overflow this land 20 kilometres from its head.

This principle has been fully recognised by the designers of canals in Upper Egypt. In the practical application there has been failure. From long experience the cultivator knows the level at which the water will stand opposite his lands corresponding to the surface level at Assouan; and it has been generally accepted that the beds of the canals where they leave the river should be at such a level that water would just enter them with a 4-metre flood at Assouan. In the largest canals the beds are sometimes ½ metre lower. If this rule had been always followed, and the canals properly constructed, even in a year like 1877 there would have been

2 metres of water entering them, and as that year the water surface in the river flowed about 1·50 metres lower than the banks, if the canal surface gained on the river 4½ centimetres per kilometre, the water in the canal would have overflowed the lands 33·3 kilometres from its head.

This may be easily seen from the following diagram :—



Now, to irrigate this upper 33 kilometres water must either be raised artificially or supplied from a canal taking its source 33 kilometres further up the Nile, and supposing the land to be level for the whole width of the valley, and the above slopes to be uniform, each canal would require to be 33 kilometres long before it began to irrigate in such a year as 1877; a state of things which would involve the country in enormous lengths of canals, to be made and maintained. Fortunately the circumstances are not so unfavourable. Throughout Egypt the valley is highest on the river bank. A flood then 1·50 metre lower than the bank is often at many places not more than 50 centimetres lower than the average level of the valley, which could therefore be inundated by a canal like the above only 11·12 kilometres long.

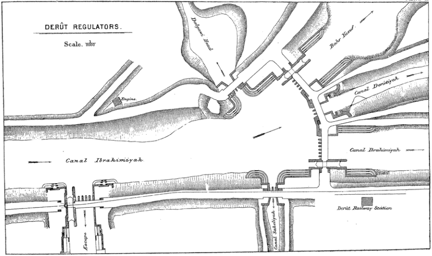
The slope of the river, moreover, is taken on its winding course, and if it is 7½ centimetres per kilometre, the slope of the axis of the valley, parallel to which the canals generally flow, is at least 10 centimetres, so that a canal with a slope of three centimetres gains on the land seven centimetres per kilometre. In a year like 1877 then it would overflow the land near the Nile at a distance of $\frac{1·50}{·07} = 21·4$ kilometres, and would overflow the most of the valley at a distance of about 10 kilometres from the head. Such a year as 1877 probably does not occur once in a century. In 1888 the water surface in the river stood about one metre below the river bank or berm, and assuming slopes as above had the canals been in thorough order, they would have begun to overflow the river bank or berm at $\frac{1·00}{·07} = 14·3$ kilometres, and the lower parts of the valley soon after entering the canal. Even in such a year as 1877, then, it would be possible to irrigate the whole area of the valley, provided the canals were all in good order, one overlapping the other. The only obstacle to this system of overlapping is that at certain places known as *Mahgars* or cliffs, especially on the eastern bank, the desert hills come right to the river edge and interrupt the series of canals. Immediately downstream of an impassable cliff the land can only be submerged in favourable years when the Nile is as high as 7·75 metres at Assouan. In years of less flood the water must be

raised artificially. On the east bank the cliffs conveniently divide the Nile Valley into systems of basins, of which there are eight to the south of Manfalut in the province of Assiout. From this point northwards to opposite Wasta there are a series of detached parcels of land separated by impassable cliffs. North of Wasta is a series of basins extending to the vicinity of Cairo.

On the west bank there are two cliffs both passed by canals opposite Karnak, and near Dendara. North of this is an extensive system extending to Assiout. From Assiout to south of Wasta the system of basins to the west of the Ibrahimieh Canal must be considered as under special conditions. From Wasta to the northern limit of Giseh is one long system in a condition by no means satisfactory. The systems are at present in every stage. In some the necessary works are nearly finished, in others they hardly exist.

During the Nile flood two quite different sorts of irrigation go on in Upper Egypt. The Nile Valley is divided into great basins, and, generally speaking, when the river rises nothing is growing in them. These basins are flooded to a mean depth of perhaps one metre, and it is not until the water has been run off them by the operation known as *sarf*, or discharge, that the land is sown with the cereal crop which ripens during the following spring. But parts of these basins, especially the Nile berm and higher lands, are under crops, sugar cane, maize or vegetables, when the river rises, and these require water in moderate and regulated quantities unlike the flooding of the ordinary basin. These flood crops in some districts form a very important part of the year's produce. The basins can only be flooded by the free flow of the water. The flood crop may be irrigated by water-raising machinery when the Nile is too low to cover the land. Plate XIV. has been prepared by Colonel Ross, and shows for each side of the river a typical system of basins with its canals, embankments and masonry works. It will be seen, beginning on the east side, that a high-level canal carried past the cliff irrigates the high berm bordering the river. All this irrigation is flood sorghum, and in years of very good Nile flood this high-level canal would not be wanted at all, as the irrigation downstream of the cliff could be done directly from the river. On the other hand, in years of defective flood, this high-level canal is the only source of irrigation for the basin A and partly of B, and in such years the flood sorghum irrigation will be extensive.

The main canal of the right bank system is taken from the river just downstream of the cliff, passes the high-level canal by a syphon, and flows northward parallel to the axis of the valley. Its waters flow freely over C and D, and if the flood is good, over B and part of A. It is carried round the next cliff, and there forms the high-level canal. The masonry works required in this system are a syphon to pass the high-level canal near its head under the main canal, bridges fitted with regulating apparatus where the different canals pass the embankments between basins, and an escape weir at the tail of the system just above the next cliff, by which to return surplus water back into the river. Many of these works already exist. The several canals should be maintained at a proper slope and section, and in order that, when the floods are favourable, the rich muddy water may freely enter the basins, *sayyalahs*, or minor canals, should be cut from the river direct into them, and these should be supplied with regulators to control the water. In years of deficient flood they would be entirely closed to keep the water inside from escaping by them back into the river. The beds of these minor canals may be a metre


DERÛT REGULATORS.
Scale. 1/2000
Engine.
Dalgawi Head
Bahr Yusuf
Canal Derûtiyah
Canal Ibrahimiyah
Canal Ibrahimiyah
Derût Railway Station
Escape
Canal Saheliyah

higher than those of the larger canals, as they will only come into use in years of good flood only.

Turning to the left or west river bank, there is the same high-level canal from the upper system carried past the cliff, which irrigates the berm basins K, P and L, as well as the large basin E in years when it cannot be flooded direct from the river. From the head of the system start two canals, one following the berm and irrigating a large series of basins which may be partly under flood crops, and the prolongation of this canal fed by the surplus water of the basins will be carried past the next cliff and form the high-level canal of the next system. Where the valley is wide, as in this diagram, this berm canal may throw off a branch to its left to take muddy water direct into the centre of the basins. The other main canal is shown passing along under the desert slopes, and this is the main channel of supply for all the basins F, G, H, R. In bad years R will only be supplied by the discharge from the upper basins.

For this system two syphons will be required near the head, a regulating bridge for the main canal, an escape weir back into the river under the tail of the system. Bridges (of which many exist) are also required where the canals pass from basin to basin. In nearly all the systems the canals require to be extended, and in some cases to be enlarged.

In the following table a forecast is given of the works necessary and their cost in order to secure Egypt from drought. It does not include provision for the bridges required on the embankments, of which a complete list cannot be given. Year by year some are added to their numbers, and although they are all necessary for the complete working of the basin irrigation, they are not all required immediately, their place being taken by cuts in the banks yearly filled up and reopened. Time has not yet allowed Lieut.-Colonel Ross to make more than a forecast for the whole work to be done. He believes it, however, ample.

Going into details, it is to be observed first the total sum arrived at is composed as follows :—

Masonry works	L.E. 228,030
New embankments (31 kilometres)	11,600
Extensions of canals (584 kilometres) . . .	305,319
Widening and deepening existing canals (476·5 kilometres)	250,690
Total . .	795,639
Add for Personnel 5 per cent. and contingencies .	39,285
Total . .	834,924

In general the works in this list are not individually of great size or importance. The following are exceptions.

Colonel Ross proposes to build a head for the Kasra canal (Girgeh) consisting of eight openings of three metres, and to pass a second canal by a syphon below its flooring. The cost of this work is L.E. 10,991.

A very large and important syphon is proposed below the great Sohagieh canal close to its head. This will cost L.E. 15,871.

Further down the same canal, near the village of Enebis, where H.E. the Public Works Minister placed a dam across the canal during last flood, it is proposed to build a regulating bridge of twenty arches, to cost L.E. 10,000.*

* Instead of carrying out this work Colonel Ross made the Tahta Canal.

A similar regulating bridge, which has long been discussed, is proposed for the Bahr Yusuf in the province of Minieh. It will have twenty-five arches, and cost L.E. 15,000.*

The long proposed escape for the Koshesha basin, where year by year the Abu Kadiga bank is cut and re-made, is estimated here at L.E. 40,000. This work was first included in the Million Estimate, but funds failed to carry it out."

The principles on which the remodelling was carried out were thus described by Colonel Ross himself in his monumental work entitled 'Notes on the Distribution of Water in Upper Egypt.' The work was printed by the Egyptian Government in 1892.

"The works designed to prevent drought in Upper Egypt have nothing new in type about them. The large expenditure from loan funds has been incurred to make the whole of Upper Egypt (where economically feasible) practically independent of a low Nile, and to make each system (as far as it is economically possible) enjoy the same advantages as the others.

There are of course parts where the land is so narrow that it would not pay to bring a long canal whose head is 32 kilometres to the south through rocks and sand. Thus the left bank of the Nile from Gebel-es-Silsilah to the head of the Killabîyah canal comes under this category.

The works necessary to prevent drought are as follows:—

1. Digging the high-level syphon canal so as to carry the water of the southern canal, red (muddy) into the next system and flowing with a proper velocity.

2. Passing this southern canal, protected on both banks, through the southern system's basin so that the white water of the southern basin may not mingle with the red water of the canal passing through the desert headland.

3. Building syphons to pass the high-level water under the canal or canals taking off direct from the Nile at the head of the system whose southern part is irrigated by the high-level canal water.

4. Deepening the canals taking from the Nile so that they may, with a low Nile of $13\frac{1}{2}\frac{1}{4}$ cubits average or 6·60 metres, in the latter part of August and in the month of September, deliver water at the rate of 100 cubic metres per diem per acre for the basins which they fill.

It is of course found that when the canals are enlarged to deliver this large supply, they will deliver far too much water in ordinary Niles. All the other works, such as canals and minor canal heads: regulating bridges in basins: escapes on to the Nile, follow as precautionary measures. By their proper use we can take into the systems at least $2\frac{1}{2}$ times the amount of water admitted in a low Nile, and thus very largely increase the supply of fertilising mud.

The only real departures made from the old native régime (which had its syphons: high-level canals: and regulating bridges and escapes to a somewhat limited extent) are:—

1. Circulation of good red water down the high-level canals during the whole of the Nile flood, and not (as was the ancient custom) passing white water from the southern basins after they were filled or at the time of discharge.

2. Carrying the canals which feed the basins along the edge of the Nile or in the

* This very necessary work has, unfortunately, not been made owing to want of funds.

middle of the basins in a deep channel. The old style was to pass the canal down the low lands of the basin, filling the last basin first and then gradually damming the regulators in succession to the south. Under this system the upper half of a basin was irrigated by the slow rise of shallow water through weeds, etc., and the mud remained in the low lands. On the new system the mass of red water flowing along the high land is delivered simultaneously into each basin at many points, thus equalising and increasing the red water distribution.

3. Excavation of Government minor feeders which have regulating heads and which irrigate the lands under flood sorghum in their upper reaches. On the old system these minor canals generally stopped in the sorghum tracts and had no outlet into the basin. On the new system an excess of water is carried in the minor canal and thrown off into the basin beyond by a masonry work in the bank separating the sorghum tract from the basin.

4. Removal of all regulators in the supply canals by the damming of which the flow might be arrested in the first 25 to 32 kilometres. In the old régime, after 8th September these regulators, generally situated at the 16th kilometre, used to be dammed to raise the water to high level by reduction of slope, and thus large deposits of silt were thrown down in the first ten kilometres and the irrigation below thrown into confusion.

The phrases Low Nile of $13\frac{10}{24}$ cubits or 6·60 metres: *Mean Nile* of $15\frac{10}{24}$ cubits or 7·50 metres: *High Nile* of $16\frac{8}{24}$ cubits or 8·0 metres, are used to denote certain averages of the height of the Nile at Aswân, to which gauge the figures are referred. The figures are taken from a study of about 18 years' records at Aswân. As most canals are not opened till the 15th August on account of the summer sorghum in the basins, the actual duration of a flood is taken to be 40 days, or 16 in August and 24 in September. *As the low Nile calculations are made on 100 cubic metres per diem on each acre covered, including evaporation*, it follows that as an acre is 4200 square metres, the depth delivered is a little under 1 metre per acre including evaporation. This is not sufficient for complete flooding, which requires ¼ more in the 40 days.

The reduced mean sea level is only used in Upper Egypt by the engineers when grading canals, etc., and on maps. The people and the engineers also all think in cubits. Thus in a Nile berm not protected, or an island, every one says, that island is not covered till 16½ cubits (8·0 metres). All this comes from observation, and it is the most convenient way of expression. For the Nile in flood is nothing more than a large canal whose volume is being constantly diminished by the offtake of the canals into the basins.

It follows from this that the August 8 metres at say Girgâ when the canals are taking off full supply is very different from the middle of September 8 metres there. There is a distinct rise of the Nile, and in many cases the 8 metres of September are found to be 25 centimetres higher than the August 8 metres. But in the calculation for discharge and statements of rise of the Nile at mean Nile, etc., detailed in each system, the figures always refer to the Nile in August, not in September.

The canal levels are fixed at their heads at 8, 9, 10 or 11 cubits or 3·50 metres, 4 metres, 4·50 metres and 5 metres. Similarly in the course of a canal the branch canals and minor canals are referred to as having their heads at 11 or 12 cubits of the parent canal, or 5 and 5½ metres.

On this grading the height of the low Nile is assumed to be 0·50 metre below

the observed highest flush of 1888, which was 7·0 metres at Aswân. This gauge of 6·50 metres is the average of the 40 days of 1888. Mean Nile is assumed to be 1 metre above low Nile and is not much verified. It is called 7·50 metres. The high Nile is assumed to be 1·50 metre above low Nile and is called 8·0 metres.

The observations made in 1888 on the flush of August 24th at Aswân, have been each year verified on upwards of 25 Nile gauges between the head of the Ramâdi canal and Asyût, and various corrections made due to original errors of observations, or lowering of the flood level due to excess of offtake from the river by the enlarged canals.

Each canal head has a Bench Mark to which it is referred.

The dimensions and levels given to the first reach of a canal must be most rigidly adhered to, as neglect of clearance of the first reach is most fatal in a bad year.

The recent remission of revenue in the province of Kena has given an enormous impulse to the cultivation of sugar cane from wells, and the people in the Bayyadîyah, Shanhurîyah, Ghilâsi systems on the east, and in the Fâdilîyah and Sâhil Farshût systems on the west, are clamorous for areas protected from flood. Their demands cannot be complied with fast enough, and it will take some years before their minor canals can be brought up to the standard of the Farshût canals, with head and tail works so necessary for the proper passage of red water.

In the province of Girgâ also, in the Khîyâm system, there is a great awakening and investment of capital in sugar cane. Also in the Beni Hîmêl east and Khalafîyah basins, and the land on the Zarzurîyah canal down to Menshîyah, the people are about to start mills. In the north Suhâg system there is not much stirring.

I again here draw attention to the great necessity of a scientific and well-thought-out delivery of the future summer supply from the reservoirs. I again protest against the folly of dislocating the entire system of Nile berm irrigation, by leading deep perennial canals through the finest and oldest parts.

For the past ten years, *the drainage of the basins* after the discharge has not been looked after much, but in the last three years increasing attention has been called to it. The local engineers have been in the habit of considering that a hollow which does not drain away, when the water retires, must be treated as a natural state of affairs. The people themselves generally relegate the drainage expenditure when proposed in council to the works to be executed, if there is money to spare.

I believe myself that these hollows, which are often 30 centimetres below the surrounding land, arise from the silting in of the land around them, owing to a better delivery of red water. In 1892, much attention has been paid to this matter and the existence of considerable areas been brought to light, in which the sowing is commonly 20 to 30 days later than the surrounding land and where, in a year like 1890, when the Nile retired very slowly, snipe have been seen in December. The principal of these hollows lie in hods Bardîs, Birbâ, 'Arâbâ, Suhâg in the south Suhâg system, and Samârnah, Banawît, 'Enebis, Kom Badr east, and Umm Dumah east basins in the north Suhâg system.

In future, the "Masfa," or channel of draining the water, should be maintained wide and fairly deep. These channels need not destroy land. They may be one metre deep and 3 to 4 metres wide. The earth is thrown out flat, not in the form of a bank; and bed, berm and bank are all culturable. Their inspection and clearance should be annually put in the "Gadwal," or list of works of the agricultural council.

The top of the bank is generally 5 metres wide to allow camels laden with dura or cotton stalks to pass each other.

The general section for slopes is $\frac{3}{2}$ on the southern side of the cross bank, and $\frac{2}{1}$ on the northern side. Similarly on the longitudinal bank the $\frac{2}{1}$ slope is put on the side next the great basin and the $\frac{3}{2}$ on the side of the smaller basin or sorghum tract. In the Nile bank the $\frac{2}{1}$ slope is on the river side. I do not see the necessity of having $\frac{2}{1}$ slopes on both sides, except where a large basin has its bank as the Nile bank. When sorghum is permanent the slope next the sorghum is only $\frac{1}{1}$. The repairs to banks are much less in proportion in the southern systems where the water in the basins is shallow. The basins in the northern systems are much deeper, and a large amount of repairs is required every year owing to the loss from wave action. For some years past the work *of pitching the banks* has been going on slowly. The pitching is done with stone in blocks of from $\frac{3}{4}$ to $1\frac{1}{2}$ cwt. each in weight, and the interstices filled in with smaller stones and chips. The result is not altogether satisfactory. The waves dashing up against the stone force water into the crevices and the spray is dashed up over the top of the stones and the water trickles down behind. This causes the removal of the bank from behind the stones and settlement occurs, and the waves then overtop the revetment and destroy the bank.

In my opinion an experiment should be tried of building the coarse native masonry walls. There are many walls standing which have never been repaired, which are at least 20 years old. By using the native mortar composed of lime and black mud from the lower parts of the basins, and the village brick burnt on the spot with dura stalks, the work would probably come to twice as much as the cost of reveting with stone, but it is far more durable, and is free from the incessant repairs necessary on the stone-faced banks.

It is a matter of great importance to have the red water of a canal which traverses the edge of a basin protected from the basin. But in many cases we have not enough money to make up the two banks. In other cases the maintenance of the made-up bank would be too expensive.

The main idea of *this submerged bank* is to have a regular channel for the low Nile water, so that before the basin reaches full irrigation level the water may flow without mingling with the white water of the basin. From observations during the Nile flood, I am confident that this submerged bank, even when beaten down by the wash of the water to a mere glacis, will give good results.

But I have observed that in cases where the excavated portion of the canal bears a too small proportion to the depth of the basin in the canal bed, there is an effort made by nature to fill in the canal with silt and reduce to a wide flat trench.

In the whole of the systems under consideration *the clearance of the canals* is the most important thing, and once that its final dimensions have been fixed, there should only be a margin of 20 centimetres allowed in the depth of silt on the bed, and a difference of $\frac{1}{20}$ in the width.

It is of course quite impossible that these immense canals should be trimmed and their slopes kept in order like a railway bank, but the most watchful attention should be paid to the wetted perimeter of the low Nile section, i.e. up to a height of three vertical metres above true bed level, when the bed is on $3\frac{1}{2}$ metres Aswân gauge. Above this it does not matter much.

The constant tendency of the upper part of the interior slope is to become flatter than $\frac{1}{1}$, and any deposit the water may lay down on it often slides off after the water has retired. There are also (owing to the immense masses of silt piled up over the slopes, and which cannot be removed owing to the great expense of removal) great slips into the canal of portions of the bank. These masses, although they do not diminish the profile of the canal much, act most harmfully in deviating the current and turning it on to the opposite bank, where another slip is the result, and in the end, if these slips are neglected, the canal becomes tortuous and a swinging motion is set up in the current, which brings on banks of silt alternately right and left.

These obstructions in the side slope are often produced by the people digging irrigation wells in the canal bed and carelessly throwing their spoil on one side. These masses of hard subsoil earth are very seldom removed.

It would be well for the subordinate engineers to exercise increasing vigilance over this matter down to the 15th kilometre of each canal of supply. Below the 15th kilometre an obstruction is not of so much consequence.

As from the above observations the side slopes of a canal are very irregular, and no definite slope, such as $\frac{1}{1}$ or $\frac{3}{2}$, etc., can be laid down, it has become the custom of late years to clean the canal whenever there is less silt than half a metre or so to a rectangular section with no side slope. In some cases the theoretical width is increased by $\frac{1}{2}$ metre on each side.

The small vertical-sided piece of earth on the toe of the side slope sinks down when the water comes, and is distributed in the angle by the water and is no obstruction whatever. The facility of calculation in contract work and avoidance of quarrels about paring slopes render this method of clearance the best that can be adopted. It is termed "Sandûq," or box fashion, by the natives. This method is also extensively in use in the Delta.

Every year efforts should be made *to straighten the great canals* of Upper Egypt when their inside slopes are not parallel to the general axis. This straightening does not mean a real rectification of unnecessary curves in original alignment, but the removal of the numerous small internal bosses from the inner slopes. The velocity of the current is very greatly improved.

The main point to which the observation of the engineer should be directed is to find out from what causes some canals silt more at their heads than others.

For *this question of silting up at the head* is not merely one of expense in clearance, but the vital question of continuity of supply is involved. Thus all canals on a 4-metre gauge have, when the bed is clear, a depth of 2½ metres on their beds in the middle of August when Aswân is at 6½ metres.

If one silts up by 15th September half a metre, and the other 1½ metre (no uncommon case), then the first one will, if the Nile falls rapidly by the 15th September to 7 metres, have one metre of water less than the other to finish up the irrigation. In other words, the canal that has 1·50 metre of silt on its head will not be able to maintain its middle reaches full, and damming up will have to be resorted to, and probably the middle reach high-level basins dependent on the canal will be slightly uncovered.

I find from observation of the practice of the Arab engineers that they aligned their canals under the following rules:—

1. The offtake shall be taken off the deep water of the Nile when it is running

along the bank from which the canal is taken, and the canal axis shall be as nearly as possible a tangent to the general curved sweep of the Nile's central current in the curved reach. To get this they have at a great cost of labour changed the head of the Kasrah canal and of Shanhurîyah canal and the Ma'annâ canal.

2. When the canal must be taken from a straight reach to irrigate the Nile berm, they take it off at a very acute angle to the Nile's axis.

3. They attach much importance to having deep water in the Nile at the offtake, and are always ready to abandon any canal head that takes off a point in the Nile where a sandbank is forming. I consider that they find from experience that the coarse sand which rolls along the bottom of the Nile bed does not enter the canal unless the Nile bed has become silted up by a sandbank to nearly the level of the canal bed. This coarse sand of course is most fatal to the permanance of supply, as it falls within the first 50 metres on entering the canal.

Of late years these unwritten maxims have been departed from, and we have had to grapple with the difficulties of canals taking off at angles varying from 45° to even 80°.

In many canals an immense silt bank forms on the southern edge inside the canal at the offtake which, before measures were taken to prevent it, used to encumber upwards of 60 per cent. of the canal profile.

This caused a rush of water through the remainder of the canal profile, and when the bed was of stronger earth than the northern slope the slope gave way, and a short bend was formed which set up the swinging action down the canal and caused the formation of alternate sandbanks right and left, or *vice versâ*, which checked the velocity and threw down silt.

A remedy has been found in reveting the canal offtake with loose stones in such a way that the upstream side is curved and retired a few metres from the downstream side (upstream and downstream are used as regards the Nile, and are generally among the natives called north and south).

The downstream side is prolonged into the Nile in the form of a spur.

(N.B.—This method is in use at the Ibrahimîyah canal offtake and has been very successful there.) The water then cannot attack the northern slope, and passes into the canal with a minimum of swing in the current.

These remarks about the offtake of canals apply with equal force to those canals which have masonry heads. Owing to the changing of the course of the Nile it is not safe to build the masonry head immediately on the river edge. They are in nearly all cases retired from 200 to 500 metres from the offtake.

As many of the observations on silt, etc., have to be made in the winter when the canals are dry, it is proper to note here that the upper 5 to 7 centimetres of a canal are not due to the low velocity of the Nile supply entering the canal. For at the end of September, when the basins are full and discharge is about to begin, and after discharge has commenced, the canals are shut down at their masonry heads or by bars of stone thrown in at a considerable distance from their offtake. And even below the point of damming off, the canal continues to flow for many days with a greatly checked velocity. Hence the visible top stratum in the cold weather is a very fine mud which is altogether a false index of the velocity of the canal in the Nile flood. On removing this mud it is seen that it generally lies unconformably on a fine grey sand whose coarseness varies in proportion to the velocity of the canal in the Nile time.

The inspection and repairs of the lower parts *of the masonry works* in Upper Egypt are more easily carried out than in the Delta. For in the Delta the floors are always covered with water, and an expensive dam has always to be made to lay the floor dry. In Upper Egypt all the works are quite dry enough for observation by the end of February, except a few of the regulators in low lands, and thus any repairs can be effected at leisure.

The chief cause, and in reality I believe the only cause of the gradual breaking up of the regulators of Upper Egypt is the gradual displacement or destruction of the work by the shock of the falling water.

The differences of water level that the works have to sustain is so slight, seldom being more than 1·5 metre, that real undermining from "creep" under the foundations is practically unknown.

In the Delta, on the other hand, the works are often exposed to differences of level of three metres. To avoid the danger of "creep" the Arab engineers used to design with extremely long horizontal floors. They had no steam pumping apparatus and could not therefore make massive curtain walls, nor did they, like the Hindus, use well blocks for foundations. So the long floor was their safeguard, and I believe that from long tradition they considered that two metres was the maximum head that a work would stand for any length of time. This is borne out by the fact that before 1884 the regulators at the end of the Delta main canals, which used to dam the fresh water from the salt water, were never used with these great heads, but an earthen dam was made upstream with incredible labour by the Corvée.

In my opinion the Delta design of the long horizontal floor prolonged beyond the wing walls, and no curtain, was employed in Upper Egypt, though in most cases a curtain of three metres was possible with a very little ordinary baling by hand.

In building, however, they omitted the downstream wing wall, and to preserve the bank from the whirlpool downstream they built a wall often 50 metres long parallel to the bank axis on the foot of the downstream slope.

Pitching with loose material was practically not used, as the art of quarrying and removal of blocks over 100 lbs. (1 kantar) was practically lost, and even to this day the contractors do not quarry in the southern parts, but merely pick up the concretionary blocks that have fallen from the mountain slopes.

The water attacks a work thus designed in the following way:—

1. By the plunging water, from between the vertical needles of regulation. eating away the bricks and lime and thus in the end making a hole in the floor under the arch.

2. By the water, when the bridge was thrown open for discharge, plunging on to the downstream prolonged floor and curling round its edge, excavating the whirlpool close up to the edge. The floor was finally undermined backwards, and fell off in blocks of one to two metres cube and sank into the pool.

3. The long wing wall was undermined by the whirlpool produced by the great rush of the water along the floor, and also by the action of the Corvée, who frequently dug borrow pits close to its foot.

Finally as the result of this constant decay of the bridge the work was declared "sick," and earthed up and abandoned. In some cases too soon, for by the addition of a very small curtain upstream and the repairs of the eroded holes, and by the

joining up into solid masses the broken floor downstream, several old abandoned bridges have been brought into use again.

Now in the future we can, by a more frequent and regularised inspection, and by allotting a sum of money for these repairs yearly, which should not be diverted to building new bridges, etc., almost guarantee that the bridge shall not be destroyed piecemeal.

There then only remains the real danger to be fought against, viz. the violent action of the water when more water is run through the bridge than was intended by the designer.

The ordinary new pattern bridges in Upper Egypt may be roughly classed as those which have 5, 4½, or 4 metres of water on the floor on the upstream side of the regulating apparatus.

The normal conditions of use of a bridge in a basin are that there is a difference of water level between the upstream side and the downstream side of one metre, and that this metre remains constant for many days, even while the basins are being emptied. The floor under the arch is horizontal, and on the same level as the floor on the upstream side of the grooves.

Taking the 4½-metres water depth as a standard, and allowing 24 cubic metres per second per arch to be the maximum permissible, we find that when there are four planks of 0·25 metre depth resting on the floor in the grooves, the discharge is 24 cubic metres per arch of 3 metres.

In a 5-metre water depth six planks should be in, and for the 4-metre depth two planks.

The following three tables [see next page] have been prepared to show the number of planks to be put in a regulating bridge to give per arch:

24 cubic metres per second;

18 cubic metres per second;

12 cubic metres per second;

with heads varying from 0·50 to 2 metres.

Example:—

The Hamad escape of five arches of 3 metres with full supply, R. L. 70·50 and floor upstream 65·50, is required to pass its full calculated discharge of 120 cubic metres per second. The head or difference between the river and the basin is 2 metres. How many planks should be in the grooves?

The escape has 70·50 − 65·50 = 5 metres water upstream of groove. Therefore under the 5-metre depth in the 24 cubic metres discharge table, the figure 10 is found, and therefore 10 planks should be in each arch.

N.B.—A plank is always reckoned 0·25 metre high. They are all made to this standard now.

It will be necessary for the Cairo authorities to give an alarm to the engineers of Upper Egypt when, according to certain indications, a low Nile is about to happen.

For there are certain works of a precautionary nature to be undertaken for the storage of water, such as shutting certain regulators in a chain of basins with earth so as to store the water in the centre of the chain. Many isolated escapes also should be shut with earth. These works are to be done by the Nile watchers who turn out about August 10th ready for the opening of the canal heads.

To enable the Ministry in Cairo to declare with confidence a bad Nile before the end of August, it must be distinctly understood that, should the Nile rise in

TABLE SHOWING THE NUMBER OF PLANKS TO BE INSERTED IN EACH ARCH OF 3 METRES OF A REGULATOR OR ESCAPE TO GIVE DISCHARGES FROM 24 TO 12 CUBIC METRES PER SECOND, AND FOR DEPTHS OF WATER UPSTREAM OF THE GROOVE VARYING FROM 5 TO 3½ METRES.

Head of Water in Metres	0·50 Head				1·00 Head				1·50 Head				2·00 Head			
	metres				metres				metres				metres			
Depth upstream of groove	5	4½	4	3½	5	4½	4	3½	5	4½	4	3½	5	4½	4	3½
To discharge 24 cubic metres per second per arch.																
No. of planks in groove .	1	open	too small	too small	6	4	2	open	8	7	4	3	10	8	6	4
To discharge 18 cubic metres per second per arch.																
No. of planks in grooves .	4	2	open	too small	8	6	4	2	10	8	6	4	11	9	8	6
To discharge 12 cubic metres per second per arch.																
No. of planks in grooves .	7	5	3	1	10	8	6	4	12	10	8	6	13	11	9	7

September to mean level or higher, there can arise no difficulty in making the change from low Nile distribution to mean Nile distribution. All that is necessary is to remove one or two planks from in front of the earthen dam which rests on them. The earthen dam will rapidly crumble away from the rush of water over it, and the regulators, etc., which have been closed with earth will, as usual, be worked for the relief of the basins and passage of water forward.

The rules I would lay down for the Cairo Ministry are thus :—

1. If on August 15th the Nile is below 13 cubits Aswân or 6·20 metres;
2. " 22nd " 14 " 6·70 "
3. " 28th " 15 " 7·20 "

the bad Nile should be declared.

The declaration should be made by telegraph to the Governors of Asyût, Girgâ and Kena, and to the Inspectors and Directors of Circles, who will at once transmit the news by telegraph to all District engineers under them.

From my experience of Upper Egypt, I feel certain that the people will not be alarmed, but only set alive early to the necessity of sowing more flood sorghum.

In fact now from want of confidence in the authorities, they frequently have panics, and when the Nile does not come on by rapid rises about August 6th–12th, or when it drops or stands still about August 20th–25th, they sow sorghum in many places quite unfit for its cultivation, and when the Nile rises after the first check, this sorghum is liable to get drowned.

The statistical information we have about the gauge at Aswân and the Nile's daily rise and fall there, commences from 1870.

The following table shows the gauges of seven typical years.

Date in August	Gauges in metres						
	1877	1880	1881	1882	1884	1886	1888
15	5·75	7·21	6·0	5·73	6·54	7·46	6·27
16	6·07	7·21	6·09	5·95	6·52	7·57	6·09
17	6·18	7·26	6·09	6·29	6·45	7·53	6·02
18	6·22	7·26	6·18	6·49	6·36	7·46	6·02
19	6·34	7·21	6·40	6·61	6·27	7·37	6·06
20	6·40	7·17	6·67	6·99	6·22	7·26	6·20
21	6·29	7·08	6·81	7·21	6·25	7·31	6·56
22	6·18	6·99	6·85	7·21	6·31	7·39	6·87
23	6·13	6·94	6·97	7·19	6·31	7·48	7·01
24	6·13	6·88	7·19	7·35	6·31	7·44	7·08
25	6·13	6·83	7·28	7·57	6·34	7·31	7·03
26	6·11	6·81	7·28	7·73	6·36	7·19	6·94
27	6·13	6·83	7·28	7·84	6·45	7·08	6·87
28	6·18	7·06	7·39	8·00	6·76	7·17	6·78
29	6·18	7·28	7·62	7·93	7·21	7·26	6·72
30	6·18	7·37	7·87	7·73	7·55	7·26	6·74
31	6·16	7·48	7·98	7·64	7·66	7·21	6·78

In 1877, the worst year of the century, the low Nile would have been declared by rule No. 1.

In 1888 it would not have been declared till August 28th, as the steady flow above 14 cubits or 6·50 gave promise of better things.

In 1880, 1882 and 1886 it would not have been declared, as the rise after the 15th was so good that considerable progress must have been made with the irrigation before August 28th.

In the year 1886, the Nile rose to above 16 cubits or 8 metres in September and removed all difficulties. In 1880 and 1882, however, the Nile was weak all through September, and though statistics are wanting in 1882, the people must have been put to very great expense by having to irrigate by lift all the Nile berms.

There were about 25,000 acres actual drought in 1880 down to Asyût.

In 1884, the low Nile would have been declared by rule 2, and much good would have been done by storage of water in the intermediate basins.

Even with the remodelled system, there is a very large width of the land immediately bordering the Nile which the people habitually irrigate by low lift, unless

the Nile has risen above 8½ metres. The irrigation of this tract is not maintained by Government, as the people, more especially in Kena and south Girgâ, have occupied it by villages. They maintain short canals running down the tract whose beds are on about 6½ metre gauge, and which therefore run absolutely dry when the Nile sinks below 6½ metres. In this category of privately irrigated Nile berm, are included all the real islands, i.e. patches of land separated from the main land, when the river has risen above 5½ metres.

N.B.—It may be noted here that in the Arabic Revenue Department, all land between the two great Nile banks is called "Gezîrah" or island, and is distinguished by the phrase "Gezîrah muttasilah" and "Gezîrah munfasilah," i.e. the island joined to and the island separated from the main land.

In this category also, may be included all the immediate berms of the great canals. For example, in the Shanhûrîyah first 15 kilometres, the whole of this length is closely cultivated by people who live in hamlets built on the spoil bank, and who cultivate for several hundred metres from the main canal by private watercourses. In this category also may be included all the strips of land bordering the desert where there is not room for a basin system with its canals, and where almost always the people lift on to the desert the water either from the Nile or from a canal parallel to the Nile whose bed, even if maintained by Government, is not lower than a 6-metre gauge.

Now all these most industrious people are much inconvenienced by the non-rising of the Nile, and especially so, *if the Nile is feeble* and below 6½ metres in the beginning of the season. For it is a well known fact that the preparation of the land for sowing takes more water to wet it for the plough than in any subsequent watering, and thus the delay in getting in the seed is very marked. So much so, that many do not get their sorghum sown until the first week in September.

To aid these people, I think the Government should:—

1. Manufacture and keep in stock Archimedean screws. It is found in the Delta that, up to 80 centimetres lift, these instruments, called in Arabic "Barîmah," give a much larger duty than any other machine. If an iron Archimedean screw could be invented with its pieces interchangeable, the pieces could be stowed away in magazines and served out in low Niles.

2. The Government should also, after September 1st, issue maize seed to the cultivators who, by reason of the struggle for irrigation, have not been able to sow before September 1st. The maize gives a very good return in sixty days, whereas the sorghum requires 100–110 at least.

The evils resulting from sorghum sown in September are: (1) Diminished yield from cold; (2) Occupation of the land to such a late date as to interfere with the sowing of lentils or barley.

By a little judicious arrangement in these two matters, Government might so much facilitate the irrigation of the lands that next low year it could righteously claim full rent. In 1888, the half of the rent was remitted on these lands in many places."

During the low flood of 1888, Mahomed Zeki Pasha, the Minister of Public Works, inspected the basin irrigation of the southern provinces, and deputed me to accompany him. I had an excellent opportunity of examining the behaviour of the basins in the only very low flood we have had since 1884, and came to the following conclusions:—

To find the necessary discharge of the basin canals in years of drought, I would calculate as follows :—

If we take $\frac{1}{10000}$ as the average longitudinal slope of country, and $\frac{1}{8000}$ as the average transverse slope of country, and consider a basin as on the average 10 kilometres long and 5 kilometres wide, which they generally are on the small canals where most of the drought area lies, and if we *just* fill the basin in a low year, the water needed to irrigate one acre is $\left(4200 \times \frac{\cdot 50 + \cdot 375}{2}\right) = 1837$ cubic metres. There will also be a loss by evaporation of 6 millimetres per day, and a loss by absorption of 2 millimetres per day over half the area for 40 days; this amounts to $(4200 \times \frac{1}{2} \times (\cdot 006 + \cdot 002) \times 40 \text{ days}) = 677$ cubic metres, giving a total of $(1837 + 677) = 2514$ cubic metres per acre in 40 days. This means a discharge of $\left(\frac{2514}{40}\right) = 63$ cubic metres per acre per day.

Colonel Ross has decided on 100 cubic metres per acre per day in a year of drought. The figures chosen by Colonel Ross are in my opinion unnecessarily high. In ordinary years, which are the rule, and in high years, which are as common as low years, the basin canals which will be remodelled will discharge an unnecessarily large supply, and finishing their work at a very early date, cause much heavier silt deposits than there will be any necessity for.

Among the local landowners the following traditions are found :—

1. In an ordinary year the basins of Esna and Kena provinces should finish their irrigation in 25 days, and Girga and Assiout provinces in 30 days.

2. Water should not be allowed to enter any basin before the 1st Misra, i.e. the 6th August.

3. If a basin, having been once filled, becomes dry before the feast of Nerûz, i.e. the 1st Tût, or the 10th September, it is considered unirrigated.

4. If a basin, having been once filled, becomes dry before the 17th Tût, i.e. the 26th September, it will yield a half crop.

5. The 17th Tût, or the 26th September, is the Salîb of the Nile, i.e. the ordinary date on which the fall of the water surface begins.

6. The southernmost basins should begin discharging after the 17th Tût, or 26th September.

7. Those basins which are discharged about the 1st Babâ, i.e. 10th October, are the most fortunate.

8. Basins which have not completed their discharge by the 20th Babâ, i.e. 29th October, will yield inferior crops.

To economise water and make it go a long way, it might be advisable in places to throw up numerous temporary banks in the basins, and thus at the time of discharge make the discharge water go much further than it otherwise would.

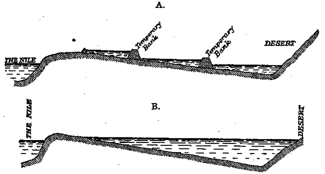
A (see page 84) is a much more economical method of irrigation than B.

The first regulator on the canals, when the regulators are less than 15 kilometres from the head, *should be kept open the whole time of flood.* By shutting these regulators, a few hundred extra acres are irrigated in the first basins at the expense of thousands of acres lower down. The loss of velocity, and consequently of discharge, is disastrous. More land is left unirrigated owing to injudicious closing of these first regulators than can ever be conceived. In a low flood like 1888, I would recommend the complete removal, on the 1st September, of the regulating

apparatus of all the first regulators, to the nearest police stations. The apparatus might be returned on the 1st October, when the discharge began.

At the time of discharge the basins should be divided into special low flood sections, and each section be discharged independently of the others. This enables the discharge to begin at twenty places at once, and to proceed leisurely from basin to basin. The depth of water in the basins after a low Nile is so small that a very poor velocity at the time of discharge can only be counted on; and hurrying the discharge from basin to basin is as wasteful as letting the basins dry up as they stand. During the low flood of 1888, this division of basins into sections, as advised by Colonel Ross, was attended with excellent results.

In a low Nile flood year it is better to fill three basins of each series well and depend on discharge water for completing the irrigation of the rest, than to fill a



large number of basins indifferently and lose much water by evaporation and infiltration.

After a low flood the landowners in the well-filled basins, where there is a chance of sowing broadcast, are anxious that the discharge should be delayed till the 10th October; while the landowners in the dry basins, depending for their supply on the discharge water, and those in the badly filled basins, where ploughing will generally have to be resorted to, are anxious that the discharge should begin as early as possible after the Salîb, that is after the 26th September.

In the interests of the State, and of the general community, it is better that the well-filled basins should be discharged early and be ploughed, than that millions of cubic metres of water should be allowed to evaporate, and the total area under crop be considerably reduced. This principle of discharging early was adopted in 1888.

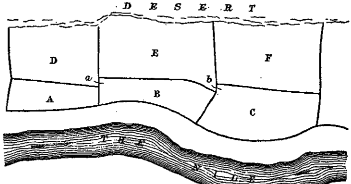
There is a possibility of the very rapid fall of the Nile in October, after a very low flood, resulting in serious loss to the millet crops. In Esna and Kena, during a very low flood, about 30 per cent. of the land is under millet, and in Girga about 25 per cent.

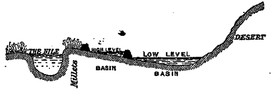
In 1888 the millet crops were sown very late owing to the flood being late. They were irrigated with a single shadoof lift up to the 1st October, when the double shadoof lift began. In many localities a third lift had to be resorted to on the 20th October. Besides this, all the high level millet canals became dry about

the 25th September, and though much clearance work was done, the rapid fall of the Nile defeated all efforts, and on the 5th October no further efforts were made to clear these canals, but the fellaheen were left to themselves. The millet crops had to be irrigated till the end of October.

The small basins along the high land bordering the Nile should be preserved, and should not be absorbed into the large basins which lie at a lower level. These small basins are very skilfully placed as shown in the sketch.

The high-lying basin B can be fed from the low-lying basin D by cutting the bank at *a*, and similarly C can be fed from E by cutting the bank at *b*. This absorption of one of these small basins into the neighbouring larger one makes it





necessary to fill the joint basin with water to a great depth in order to cover the whole area. The natural result is that during flood the waves are far higher, and the wash on the banks more dangerous. There is also a very sensible diminution of the millet crop, which runs great risk of being drowned out when sown inside the basins on the elevated parts. The fellaheen in years of drought prefer a crop of millets followed by a winter crop, to the single winter crop ordinarily sown in the basins.

During a two years' examination of the land rents in Egypt, I made the following notes on basin irrigation as I saw it in 1895 and 1896.

The four main elements on which rents are based are the following:—

1. A plentiful supply of red water between August 15 and October 10. This fixes the quality of the soil.

2. Plentiful subsoil water at a moderate depth below the surface of the ground.

3. The presence of ancient ruins, or of nitrate deposits in the deserts.

4. The timely discharge of the water from the basins.

These elements are not placed in order of importance, nor indeed can there be any such order. In el-Iswid basin of Geeza Mudirieh, the rise of spring level, owing to the regulation of the Barrage, is being taken advantage of to convert this part of Geeza into a perennial tract like Kalyoubia or Southern Menoufia. No canals are needed. The change is being effected by well irrigation. Farmyard manure is plentiful, and basin irrigation is becoming unnecessary. Here subsoil water is the main factor. In the Beni Smia and Enêbis basins, the red water supply is so plentiful and timely that the rentals of the basins approach that of good perennial land. Again, in the deserts bordering Edfu and Esna, the nitrate deposits are so plentiful, that, with their aid, some of the poorest irrigated land in Egypt is rendered capable of supporting a dense population. Round Abydos as a centre, with numerous ruined cities and good subsoil water, there is a cultivation as intense and a population as dense as in Menoufia. Northern Assiout and northern Geeza would produce better crops if the basin water could be more quickly discharged; while southern Beni-Suef and northern Minia would be considerably improved if the water were allowed to stand much longer on the basins.

The most contented parts of Upper Egypt are the left bank of the Nile from Luxor to Abutîg, and the right bank from Maala to the northern end of Markas Abnûb. Here was spent the mass of the special drought (Sharâki) loan. Colonel Ross's works, with local and insignificant exceptions, have insured good and timely irrigation.

Gêdi, or summer millets, permit of the basins being double cropped and yet thoroughly irrigated and washed. It might be encouraged wherever red water is obtainable. "*Nabâri,*" *or flood millets,* on the other hand, interfere with basin irrigation, and end in the lands becoming salted both from infiltration and from the deleterious salts contained in the nitrate deposits and in the ancient ruin manures which are very freely applied to the millets. The increase of Nabâri millets does not mean any rise in the rentals of the basins, while the increase of Gêdi does. I have heard Mr. Wilson express almost exactly the same opinion as the fellaheen on this subject.

South of Luxor, irrigation will always be difficult, as the slope of the Nile valley and the Nile itself are the same, and the canals do not gain on the river, owing to alignment, as they do lower down. The new works have improved the irrigation during low flood years, but they have, on the contrary, deprived the basins of much red water irrigation in years of high flood. Special works will have to be made here for passing high floods into the basins, or this land will continue to deteriorate.

The fellaheen classify the basin canals as "muddy" or "sandy," according as the water they carry is rich in slime or sand. They naturally prefer the muddy canals, of which Sohagia is the arch type. Such canals, they say, take off severe curves of the Nile, and have no shoals or shifting islands near their heads. The sandy canals are of the type of the Girgawia (the worst of all) and the Ibrahimia, which take off straight reaches with shifting shoals near their heads. Village headmen have frequently informed me that they would far sooner have their lands in the fourth or fifth basin of the Sohagia than in the first of the Ibrahimia or the Girgawia, which enjoy a very bad reputation. They propose the removal of their heads, but that is practically out of the question.

The training of the Nile for 7 or 8 kilometres upstream of the heads of canals which are encumbered with shoals, might suffice to improve the canals.

It has already been stated that the rents of the lands south of Assiout, where Colonel Ross spent nearly all the drought prevention loan, are steadily rising and will continue to rise. This additional wealth is making itself evident in the construction of wells for the utilisation of the subsoil water. *Subsoil water* will prove a mine of wealth to the country in the future when the manure question has been settled. An important landed proprietor in Girga told me that the works had so improved the deposits on his land that he had begun to cover his property with masonry wells, and in 1895–96 had obtained 8 ardebs of beans per acre in the winter, and 19 ardebs of sorghum per acre in the summer after clover.

The basins of northern Assiout, Minia and Beni-Suef are never liable to drought as they can always be irrigated with escape water; nothing was consequently done towards their improvement out of the drought loan. Very many of these basins are, however, among the poorest in Egypt. With the exception of Ashmunên at one end and Ahnas at the other, there are practically no ancient ruins for manure, and the deserts supply no nitrates. The amount of red water received in flood must always have been deficient, as the quality of the soil is often very inferior, while the construction of the Ibrahimia canal in 1874 cut them entirely off their red water supply. The numerous red water feeders constructed by Major Brown out of ordinary funds have begun to give many of them a fresh lease of life in years of high flood, but in years of low flood they receive only 5 or 6 days' irrigation with white water discharged from the upper basins. The basins on the west of the Yusûfi in Minia which have no red water feeders have a mean rental of 180 piastres * per acre, while the basins on the right bank which have been provided with red water feeders have had their mean rents raised to 235 piastres, or a gain of 55 piastres per acre. If these lands were provided with permanent red water feeders on the Girga and southern Assiout scale, the rents would rise to 300 and 325 piastres per acre as they have in Girga, or a further gain of from 65 to 90 piastres per acre. No irrigation work in Egypt to-day would yield a larger profit in proportion to the money spent than the improvement of the basin systems of northern Assiout, Minia and Beni-Suef.

During the preparation of the reservoir projects, the irrigation officers of Upper Egypt and those of the reservoir survey, took discharges of all the basin canals of Upper Egypt in 1892 (a very high year), and in 1893 (a moderately low one). The results are recorded in the two following tables. It will be noted that in 1892, with the Assuân gauge reading 8·80 metres on the 10th September, the basin canals were discharging 3630 cubic metres per second, or 30 per cent. of the total discharge of 12,100 cubic metres per second. In 1893, with the Assuân gauge reading 7·00 metres on the 15th August, the canals were discharging 2040 cubic metres per second, or 27 per cent. of the total discharge of 7600 cubic metres per second. The Cairo gauge on this latter date was 5·8 metres, and the discharge 5550 cubic metres per second. The maximum discharges of the Ibrahimia and Sohagia canals in 1894 were 740 and 520 cubic metres per second respectively.

* £1 = 100 piastres.

TABLE I.

DISCHARGES OF THE CANALS IN UPPER EGYPT IN 1892.

Canal Discharges between Assuân and Assiout.

Name of Canal	August				September					
	15	20	25	31	5	10	15	20	25	30
Ramadi	55	66	80	76	82	85	89	91	..	..
Um-Ads	8	9	12	13	16	18	20	..	..	..
Afsûn	25	29	37	39	42	43	45	..	..	..
Fadilia	12	26	44	49	52	55	50	..	..	..
Toukh	10	19	37	42	44	58	60	..	..	..
Rannan	28	36	53	59	62	67	70	..	..	..
Dumrania	26	35	56	62	65	70	74	..	..	..
Rashwania	35	41	58	61	64	70	73	..	..	..
Kasra	49	62	104	133	138	150	150	..	..	..
Zarzria	24	30	64	76	77	90	90	..	..	..
Girgawia	54	59	84	95	96	120	120	..	..	..
Sohagia	380	386	470	485	492	520	500	..	..	..
Tahta	44	45	66	75	77	82	85	..	..	..
Shatura	25	24	39	47	49	45	40	..	..	..
Ibrahimia	460	440	540	600	640	700	740	..	..	..
Waladia	6	6	14	20	24	24	24	..	..	..
Minor canals	10	15	20	30	30	30	20	..	..	..
Total left bank	1250	1320	1790	1980	2060	2250	2270	91	..	..
Kilibia	6	11	17	20	24	28	32	..	..	..
Maala	5	5	18	22	26	30	32	..	..	..
Bayadia	30	36	62	69	77	85	90	..	..	..
Shanhuria	46	55	98	108	116	120	125	..	..	..
Shekha	5	6	10	11	12	12	12	..	..	..
Gilasi	19	30	58	64	68	70	72	..	..	..
Samatha	12	19	41	48	52	60	60	..	..	..
Tarif	10	15	20	25	25	25	25	..	..	..
Hawis	15	22	38	41	44	51	56	..	..	..
Ahaiwia	10	15	20	25	25	25	25	..	..	..
Isaiwia	35	35	55	60	63	70	70	..	..	..
Khizindaria	63	62	86	96	98	110	95	..	..	..
Maanah	35	41	58	67	71	80	85	..	..	..
Sant	6	7	8	10	10	12	12	..	..	..
Minor canals	4	8	12	15	15	15	15	..	..	..
Total right bank	300	370	600	680	730	800	810	..	..	..
Total both banks	1550	1690	2390	2660	2790	3050	3080	..	..	..

TABLE I.—*continued.*

Canal Discharges between Assiout and Cairo.

Name of Canal	August				September					
	15	20	25	31	5	10	15	20	25	30
Beni-Husain	13	16	20	30	35	40	..	..	..	..
Abu-Bakra	53	38	60	80	85	93	..	..	..	..
Sultani	18	10	20	37	38	40	..	..	..	..
Nina	9	5	10	20	20	20	..	..	..	..
Bahabshin	12	8	14	27	28	33	..	..	..	..
Magnuna	15	15	22	40	45	45	..	..	..	..
Kushesha	70	70	70	70	70	70	..	..	..	..
Zawia	11	7	16	27	28	33	..	..	..	..
Girza	40	38	70	95	100	100	..	..	..	..
Zumr	13	12	14	19	20	19	..	..	..	..
Minor canals	2	2	4	4	4	4	..	..	..	..
Total left bank	260	220	320	450	480	500	..	..	..	..
Aly Bey	14	13	28	33	20	18	..	..	..	..
Khassâb	19	14	25	35	40	46	..	..	..	..
Minor canals	7	6	12	12	14	14	..	..	..	..
Total right bank	40	30	70	80	80	80	..	..	..	..
Total both banks	300	250	390	530	560	580	..	..	..	..

Canal Discharges between Assuân and Cairo.

Left bank	1510	1540	2110	2430	2540	2750	..	..	..	..
Right bank	340	400	670	760	810	880	..	..	..	..
Total	1850	1940	2780	3190	3390	3630	..	..	..	..
Assuân gauge	6·7	7·4	8·3	8·3	8·6	8·8	8·7	..	..	..
Assiout gauge	6·1	5·9	6·8	7·2	7·4	7·7	8·1	..	..	..
Cairo gauge	5·8	5·5	5·8	6·7	7·0	7·2	7·7	..	..	..

TABLE II.

DISCHARGES OF THE CANALS IN UPPER EGYPT IN 1893.

Canal Discharges between Assuân and Assiout.

Name of Canal	August				September						October				
	15	20	25	31	5	10	15	20	25	30	5	10	15	20	25
Ramadi	50	56	58	56	55	60	64	61	64	61	..	..	..	..	..
Um-Ads	10	12	12	12	13	14	15	15	15	15	..	..	..	..	..
Asfun	28	33	34	33	31	33	35	33	34	33	..	..	..	..	..
Fadilia	17	24	26	26	22	24	29	24	22	20	..	..	..	..	..
Toukh	19	24	26	27	21	24	24	22	27	26	..	..	..	..	..
Rannan	20	26	29	28	25	25	30	27	30	28	..	..	..	..	..
Dumrania	33	39	44	43	39	41	46	43	46	44	..	..	..	..	..
Rashwavia	45	52	60	55	50	53	68	60	65	60	..	..	..	..	..
Kasra	70	72	82	79	72	76	87	82	87	82	..	..	..	..	..
Zarzuria	38	44	47	46	45	47	52	46	52	46	..	..	..	..	..
Gergawia	55	55	59	58	56	56	62	57	62	57	..	..	..	..	..
Sohagia	390	380	400	390	350	360	420	390	430	410	..	..	..	..	..
Tahta	45	46	47	46	44	45	51	44	52	47	..	..	..	..	..
Shatura	20	23	26	25	22	17	28	25	29	28	..	..	..	..	..
Ibrahimia	520	520	560	560	540	540	600	580	600	600	..	..	..	..	..
Waladia	10	11	12	12	11	11	11	12	12	12	..	..	..	..	..
Minor canals	10	15	20	20	20	20	20	20	20	20	..	..	..	..	..
Total left bank	1380	1430	1550	1510	1420	1440	1640	1540	1650	1590	..	..	..	..	..
Kilibia	11	13	15	14	14	15	17	16	16	16	..	..	..	..	..
Maala	11	12	13	12	13	14	16	16	16	16	..	..	..	..	..
Bayadia	36	44	48	46	40	45	52	44	42	30	..	..	..	..	..
Shanhuria	56	64	69	63	62	64	70	50	40	30	..	..	..	..	..
Shekhia	6	7	9	8	6	6	4	5	6	6	..	..	..	..	..
Gilasi	24	32	34	32	29	30	35	31	34	33	..	..	..	..	..
Samatha	17	24	27	25	22	24	28	25	27	26	..	..	..	..	..
Tarif	12	14	16	15	14	15	17	16	17	16	..	..	..	..	..
Hawis	24	27	29	29	27	27	29	27	25	16	..	..	..	..	..
Ahaiwia	15	16	16	16	12	12	10	7	4	4	..	..	..	..	..
Isawia	30	37	40	37	37	39	40	40	43	40	..	..	..	..	..
Khazindaria	60	62	67	66	60	60	66	65	55	50	..	..	..	..	..
Maanah	29	30	32	32	29	32	33	34	24	24	..	..	..	..	..
Sant	6	6	9	8	7	7	7	7	7	7	..	..	..	..	..
Minor canals	4	7	10	10	10	10	10	10	10	10	..	..	..	..	..
Total right bank	340	400	430	410	390	400	430	390	370	320	..	..	..	..	..
Total both banks	1720	1830	1980	1920	1810	1840	2070	1930	2020	1910	..	..	..	..	..

TABLE II.—*continued.*

Canal Discharges between Assiout and Cairo.

Name of Canal	August				September						October				
	15	20	25	31	5	10	15	20	25	30	5	10	15	20	25
Beni Husain	17	18	19	20	14	12	16	17	17	17	..	..	..	..	..
Abu-Bakra	63	50	63	64	60	58	68	65	64	64	..	..	..	..	..
Sultani	17	16	17	17	16	15	17	17	17	17	..	..	..	..	..
Nina	9	8	9	10	10	9	9	9	9	9	..	..	..	..	..
Bahabshin	11	9	11	12	12	10	12	11	13	14	..	..	..	..	..
Magnuna	21	20	20	20	24	23	28	29	30	30	..	..	..	..	..
Kushâska	70	70	50	30	0	0	0	0	0	0	..	..	..	..	..
Zawia	11	8	13	12	13	12	13	15	16	17	..	..	..	..	..
Girza	50	45	50	55	60	60	50	50	40	30	..	..	..	..	..
Zumr	10	10	10	10	6	6	7	12	14	15	..	..	..	..	..
Minor canals	2	2	2	2	2	2	2	2	2	2	..	..	..	..	..
Total left bank	280	260	260	250	220	210	220	220	220	220	..	..	..	..	..
Ali bey	16	20	27	28	15	12	15	17	20	20	..	..	..	..	..
Khassâb	20	20	20	22	19	15	19	15	15	18	..	..	..	..	..
Minor canals	6	6	6	6	7	7	7	7	7	7	..	..	..	..	..
Total right bank	40	50	50	60	40	30	40	40	40	50	..	..	..	..	..
Total both banks	320	310	310	310	260	240	260	260	260	270	..	..	..	..	..

Canal Discharges between Assuân and Cairo.

Left bank	1660	1690	1810	1760	1640	1650	1960	1760	1870	1810	..	..	..	..	..
Right bank	380	450	480	470	430	430	470	430	410	370	..	..	..	..	..
Total	2040	2140	2290	2230	2070	2080	2330	2190	2280	2180	..	..	..	..	..
Assuân gauge	7·0	7·3	7·4	7·3	7·2	7·5	7·6	7·4	7·1	7·3	7·1	7·3	6·9	6·3	6·0
Assiout gauge	6·2	6·2	6·4	6·3	6·2	6·3	6·5	6·5	6·6	6·6	6·4	6·5	6·7	6·7	..
Cairo gauge	5·8	5·6	5·9	6·0	6·0	5·8	6·0	6·0	6·1	6·3	6·2	6·1	6·4	6·5	2·7

By plotting these discharges and drawing curves, and applying them to the minimum, mean and maximum years, it will be found that the 1,435,000 acres of basins will receive in a minimum year 1400 cubic metres per second for 45 days, in a mean year 2100, and in a maximum year 3200.

This means that in a minimum year 1 cubic metre per second will irrigate 1030 acres; in a mean year 690 acres; in a maximum year 450 acres; or in other words, in a minimum year 1 acre will receive in 24 hours 83 cubic metres; in a mean year 125 cubic metres; in a maximum year 190 cubic metres.

All the basins will not, however, receive equal amounts. Taking a mean year as a basis, the following table will give the quantities received by the different systems of basins.

Name of Basin System	Area in acres	Discharge in cubic metres per second	Cubic metres per acre per 24 hours	Remarks
Assuân (minor) .	5,000	5	80	For 45 days in a mean year.
Ramadi-Farshût	187,000	260	120	" " "
Kena, right . .	114,000	200	150	" " "
Girga, right . .	48,000	80	150	" " "
Kasra-Girgawia .	112,000	220	170	" " "
Sohagia-Delgâwi	324,000	640	170	" " "
Waladia . . .	30,000	25	70	" " "
Assiout, right .	73,000	110	135	" " "
Yusufi	421,000	460	90	" " "
Minia and Beni-Suef, right . .	16,000	10	50	" " "
Geeza, left . .	80,000	70	75	60 to 70 days in a mean year.
Geeza, right .	25,000	20	70	" " "
Total . .	1,435,000	2100	125	Mean year.

The following lists of basins have been taken in part from Colonel Ross' figures, in part from information supplied by the Inspectors-General of Irrigation, in part from information gained during the land tax adjustment commissions.

The basins have been classified by systems which are recorded on the large scale map of Upper Egypt, Plate XIII. For each basin there is recorded the reduced level of the full irrigation water surface, the number of acres of land in the basin, the approximate areas of summer and flood sorghum, and the mean renting value. Finally there is added the quality of land in the basin. This table will be made considerable use of when the extension of perennial irrigation is under consideration. The best and most prosperous basins are undoubtedly: 1. Samhûd, Bardes and Birba

round the ancient Abydos, with their rich annual deposits of Nile mud, their plentiful subsoil water, and the proximity of valuable manure in the ruins of ancient cities; (2) Sohag, Anêbis, Um Duma, Beni Smia and Zemnar, with their rich annual deposits of mud and plentiful subsoil water; (3) Delgawi and Ashmunen basins in the north of Assiout, the northern half of Koshêsha basin at the tail of the Yusûfi canal series, and the Iswid basin opposite Cairo, with its excellent position, its plentiful and convenient subsoil water, and its proximity to the manure heaps of ancient Cairo. The best basin lands rent at 5*l.* per acre; good lands at 4·0*l.*; ordinary basins at 2·50*l.* to 3·50*l.* per acre; and the poor basins are from ·50*l.* to 1·50*l.* per acre. It may be noted here that land worth 3·0*l.* per acre in Assiout would be worth only 2·50*l.* per acre in Kena, owing to its distance from the sea.

The renting values per acre in pounds and decimals of a pound represent the value at which land is sublet to the fellaheen by large proprietors, or by the fellaheen to one another. The best land in each basin is generally at the north end, where most of the mud is ordinarily deposited, and the poorest land is at the south end, where the depth of water is insignificant and all the sand is ordinarily deposited if the water is charged with silt. The poorest basins are those which get scarcely any deposit of sand or mud.

LIST OF BASINS IN UPPER EGYPT.

Name of Basin	R.L. Full Irrigation Level	Area in acres	Mean Renting Value in £	Province	Acres of Flood and Summer Crops, 1898			
					Sugar-cane	Cotton	Summer Sorghum	Flood Sorghum
Banbân System—left bank of the Nile.								
Banbân . . .	90·60	1,700	1·80	Assuân	..	..	220	80
Ramâdi System—left bank of the Nile.								
Ramâdi, S. . .	86·75	1,200	2·00	Assuân	..	..	90	240
Ramâdi, N. . .	85·70	3,800	2·50	"	10	..	30	2,400
Edfu-Kilh . .	85·30	10,000	2·80	"	20	..	510	2,030
Bassilya . . .	..	2,000	2·50	Kena	20	..	80	1,550
Sabaya . . .	82·60	4,500	2·50	"	50	..	60	2,600
Namasa . . .	81·80	6,400	2·50	"	10	..	120	1,430
Esna, S. . . .	81·45	3,800	2·50	"	5	..	120	920
Esna, N. . .	81·00	4,200	2·50	"	5	..	100	100
Matäâna Enclosures	..	7,900	3·00	"	1,900	..	..	..
Wadi el Ginn and Asfûn . .	79·85	8,100	2·50	"	..	..	490	3,530
Kiman and Tafnis .	79·85	2,000	2·50	"	..	..	..	..
		53,900			2,020		1,600	14,800

LIST OF BASINS IN UPPER EGYPT—*continued.*

Name of Basin	R.L. Full Irrigation Level	Area in acres	Mean Renting Value in £	Province	Acres of Flood and Summer Crops, 1898			
					Sugar-cane	Cotton	Summer Sorghum	Flood Sorghum
Asfûn System—left bank of the Nile.								
Mahamîd . .	79·00	2,200	2·50	Kena	..	..	..	..
Rîtî . . .	78·50	2,500	2·50	„	..	..	850	..
Makharr. . .	77·35	2,200	2·50	„	..	..	900	..
Armant Enclosures .	..	7,500	3·00	„	3,500	..	..	4,000
Dabaya . . .	77·10	9,600	2·50	„	..	..	3,500	60
		24,000			3,500		5,250	4,060
Fadilia System—left bank of the Nile.								
Akhmas, Kamûla, &c.	76·65	2,300	2·30	Kena	90	..	150	500
Danfîk . . .	75·85	8,700	2·70	„	70	..	870	180
Khattara. . .	75·10	1,500	2·70	„	5	..	100	..
Tukh . . .	75·00	2,000	2·70	„	..	..	80	..
Abu Ghort . .	74·80	600	2·80	„	80	..	..	50
Zawaida . . .	74·30	3,000	2·70	„	5	..	190	110
Der-Ballâs . .	74·10	3,000	2·70	„	..	..	..	20
Tawairat . .	73·30	1,600	2·70	„	..	..	..	50
		22,700			250		1,390	910
Sahil Farshût System—left bank of the Nile.								
Taramsa . .	72·95	600	2·80	Kena	..	..	80	450
Dendera. . .	72·60	2,800	3·10	„	..	..	150	30
Marashda . .	71·10	2,000	2·70	„	40	..	..	40
Rannan West . .	70·95	1,100	2·70	„	..	..	..	..
Rayyasia Enclosure	..	3,800	3·00	„	190	..	60	220
Wahf . . .	70·50	4,000	3·00	„	130	..	100	140
Hew . . .	69·80	7,900	2·70	„	160	..	90	150
Kammana . .	68·00	1,700	3·20	„	320	..	50	320
Der . . .	68·00	1,000	3·20	„	530	..	90	350
Dahasa . . .	67·00	5,600	3·20	„	250	..	430	360
Bakhanis . .	67·20	1,700	3·00	„	..	..	300	..
Kom el Ahmar .	66·75	1,300	3·00	„	20	..	200	100

LIST OF BASINS IN UPPER EGYPT—*continued.*

Name of Basin	R.L. Full Irrigation Level	Area in acres	Mean Renting Value in £	Province	Acres of Flood and Summer Crops, 1898			
					Sugar-cane	Cotton	Summer Sorghum	Flood Sorghum
Sahil Farshût System—continued.								
Rakaik, S.	67·00	2,000	3·00	Kena	250	..	150	450
Rakaik, N.	66·75	4,000	3·10	"	250	..	100	420
Sahara, E.	67·50	1,500	2·90	"	..	..	..	60
Sahara, W.	67·00	1,700	2·90	"	..	..	..	70
Samhûd	66·50	30,100	3·60	"	210	..	3,200	400
		72,800			2,350		5,000	3,560
Kasra Zarzuria and Girgawia Systems—left bank of the Nile.								
Beni Himel, E.	66·10	3,400	3·60	Sohag	300	..	470	350
Beni Himel, W.	65·70	3,000	3·60	"	250	..	390	300
Bardis, E.	65·15	18,300	3·40	"	100	..	2,200	400
Bardis, W.	65·25	2,000	3·60	"	20	..	500	200
Bardis, S.W. of Rashwania	65·45	..	3·60	"	100	..	250	300
Khalafia	64·75	4,500	3·10	"	100	..	400	150
Birba Enclosure	64·30	600	3·40	"	..	..	100	..
Birba, E.	64·00	5,700	3·50	"	50	..	2,500	200
Birba, W.	63·85	8,400	3·60	"	..	..	850	20
Baliana	..	5,000	3·30	"	1,800	..	..	600
Bayâdi	64·75	1,500	3·20	"	..	..	200	150
Humêdi	64·50	3,000	3·20	"	50	..	410	200
Asairat Enclosure	64·15	1,800	3·00	"	10	..	300	350
Sahil Tukh	64·10	300	2·80	"	10	..	..	50
Hikr	63·85	1,300	2·80	"	10	..	40	130
Araba, E.	63·80	2,700	3·00	"	10	..	350	..
Araba, W.	63·70	8,700	3·50	"	10	..	1,700	100
Kharifa Lahaiwa	63·60	2,400	3·20	"	..	..	200	200
Kawamil Enclosure Kawamil	62·80 62·80	8,200	3·30	"	20	..	720	300
Bagiya	63·40	700	3·30	"	..	..	40	80
Menshia, E.	63·10	1,700	3·30	"	..	..	150	50
Menshia, W.	63·15	3,500	3·30	"	..	..	600	..
Gezirat Muntasar	63·10	2,600	3·30	"	40	..	50	300
Sohag, E.	62·50	4,200	3·40	"	..	..	250	..
Sohag, W.	62·50	18,200	3·60	"	80	..	2,000	810
		111,700			2,960		14,670	5,240

LIST OF BASINS IN UPPER EGYPT—*continued.*

Name of Basin	R.L. Full Irrigation Level	Area in acres	Mean Renting Value in £	Province	Acres of Flood and Summer Crops, 1898			
					Sugar-cane	Cotton	Summer Sorghum	Flood Sorghum
Sohagia, Tahtawia, Delgawi System—left bank of the Nile.								
Araba-Idfa Enclosure	61·50	500	3·40	Sohag	10	..	30	100
Araba-Idfa . .	61·30	8,800	3·40	”	70	..	1,350	70
Gerezat Gehena .	60·00	4,300	2·80	”	10	..	470	50
Kilfau . . .	61·70	2,000	3·30	”	..	..	..	..
Baga . . .	61·25	1,500	3·30	”	20	..	50	400
Gezirat Muâfin .	61·25	2,500	3·30	”	50	..	210	800
Muâfin Enclosure .	60·70	500	3·30	”	10	..	100	250
Aulad Nusêr . .	61·25	600	3·30	”	10	..	40	300
Naga Tammam .	60·80	2,400	3·30	”	..	..	40	230
Samarna . .	60·35	9,300	3·30	”	30	..	730	600
Banawit . . .	59·50	10,600	3·50	”	10	..	820	330
Beni Hillal . .	59·50	2,000	3·30	”	10	..	30	160
Enebis . . .	59·10	8,700	3·70	”	30	..	760	30
Sawarna . . .	59·00	1,400	3·00	”	..	..	120	50
Banahu Banga .	{59·50 58·40}	4,300	3·70	”	50	..	720	250
Kom Badr, E. .	58·00	8,700	3·60	”	10	..	1,070	190
Kom Badr, W. .	58·20	11,200	3·40	”	20	..	1,450	290
Zeinuddin Enclosure	..	900	3·70	”	10	..	..	400
Shattûra . . .	57·75	1,800	3·40	”	30	..	..	730
Mishta . . .	57·60	1,100	3·40	”	10	..	80	290
Madmar, E. . .	57·60	1,400	3·30	”	..	..	110	100
Madmar, W. . .	57·40	5,000	3·40	”	..	..	460	40
Tima, E. . .	57·10	900	3·20	”	..	..	..	..
Kaw . . .	57·40	1,300	3·20	”	..	..	40	900
Sahil Kaw . .	..	1,200	3·10	”	..	..	..	200
Umduma, E. . .	57·10	13,700	3·70	”	..	..	2,140	220
Umduma, W. . .	57·00	9,600	3·60	”	..	..	1,450	660
Duwêr . . .	56·05	10,300	3·50	Assiout	..	..	880	..
Beni Smia . .	55·50	32,400	3·80	”	40	..	3,920	110
Zennaar . . .	53·60	34,900	3·80	”	30	..	1,000	60
Malla . . .	52·20	3,000	3·30	”	..	..	60	50
Masrâwi . . .	51·60	5,200	3·20	”	..	..	530	50
Kelbi . . .	50·30	19,800	3·20	”	..	..	450	70
Beni Rafai . .	49·30	12,700	3·20	”	..	..	1,100	..
Maharrak . .	48·00	23,000	3·10	”	140	..	1,800	30
Kusya . . .	47·25	8,000	3·10	”	70	..	1,100	20
Delgawi . . .	46·00	50,000	3·50	”	780	..	6,400	820
Tuna . . .	43·60	6,000	3·50	”	120	..	900	90
Beni Khalid . .	42·70	3,100	3·70	”	60	..	600	60
		324,600			1,630		31,010	9,000

LIST OF BASINS IN UPPER EGYPT—*continued.*

Name of Basin	R.L. Full Irrigation Level	Area in acres	Mean Renting Value in £	Province	Acres of Flood and Summer Crops, 1898			
					Sugar-cane	Cotton	Summer Sorghum	Flood Sorghum
Waladia Canal System—between the Nile and the Ibrahimia Canal.								
Waladia . . .	52·20	1,900	3·10	Assiout	..	..	..	150
Beni Husain, E. .	51·70	1,600	3·10	„	..	..	50	..
Beni Husain, W. .	51·70	4,300	3·20	„	..	..	280	230
Manfalût, S. . .	50·80	8,700	3·20	„	10	..	90	430
Manfalût, N. . .	49·50	6,700	3·60	„	250	..	300	590
Fazara and Mâsara .	47·80	3,000	3·40	„	20	..	150	540
Mandara . . .	46·70	3,700	3·40	„	80	..	130	370
		29,900			360		1,000	2,310
Right bank basins of the Yusufi Canal System.								
Tanûf . . .	46·00	8,100	3·20	Assiout	20	..	800	640
Ashmunên . .	44·00	36,100	3·60	„	1,490	..	3,020	1,750
Itka . . .	43·20	8,500	3·40	„	80	..	800	80
Tahanashawi . .	41·00	36,700	3·20	Minia	40	..	500	1,500
Kurûn . . .	39·35	8,600	3·00	„	20	..	80	120
Tahâwi . . .	38·85	7,900	2·70	„	20	50	100	80
Dêri . . .	38·20	8,500	2·40	„	20	..	40	..
Mangatîn . .	37·10	3,700	2·30	„	..	..	..	..
Membal . . .	36·70	9,000	2·30	„	..	60	30	..
Bardanuha . .	35·75	11,000	2·10	„	..	..	300	150
Garnûsi . . .	35·25	18,500	2·60	„	..	20	250	100
Salakôsi . . .	33·75	5,500	2·60	„	..	30	80	80
Sultâni . . .	30·34	25,500	2·70	Beni-Suef	..	220	550	..
Nina . . .	29·38	20,100	2·80	„	..	850	450	..
Nuêra . . .	28·38	20,100	2·70	„	..	200	800	..
Koshêsha . .	26·75	75,400	{2·00 / 4·00}	„	..	1,300	3,500	..
		303,200			1,690	2,730	11,300	4,500
Left bank basins of the Yusufi Canal System.								
Minia Province .	..	84,000	1·80	Minia	10	1,300	1,900	5,000
Beni-Suef Province .	..	21,000	2·30	Beni-Suef	..	3,150	900	1,000
		105,000			10	4,450	2,800	6,000

LIST OF BASINS IN UPPER EGYPT—*continued.*

Name of Basin	R.L. Full Irrigation Level	Area in acres	Mean Renting Value in £	Province	Acres of Flood and Summer Crop, 1898			
					Sugar-cane	Cotton	Summer Sorghum	Flood Sorghum
Rikka System—left bank of the Nile.								
Rikka	25·60	12,400	3·20	Beni-Suef	60	..	1,100	..
Left Geeza System—left bank of the Nile.								
Maarkab	23·90	5,500	3·30	Geeza	100	..	590	400
Tahma	22·70	5,500	3·70	”	2,200	800	1,110	260
Dahshur	21·90	12,200	3·70	”	1,900	900	2,060	140
Sakkara	20·60	9,200	3·50	”	10	30	2,300	..
Shabramant	19·50	13,000	3·40	”	..	..	2,270	..
Manshia	17·60	7,600	3·20	”	..	100	550	540
Geeza and Tirsa	..	3,000	3·40	”	..	150	20	250
Iswid	16·40	24,200	3·50	”	..	750	1,970	..
		80,200			4,210	2,730	10,870	1,590
Assuân Province Basins—right bank of the Nile.								
Khattara	92·90	400	2·00	Assuân	..	..	50	30
Darau	90·75	1,200	2·00	”	..	..	130	80
Iglit	89·15	500	1·80	”	..	..	70	50
Selwa	..	600	1·70	”	..	..	..	..
Ridisia	85·70	2,900	2·00	”	..	..	100	2,250
		5,600					350	2,410
Killabia System—right bank of the Nile.								
Hilla-Der	81·20	4,800	2·20	Kena	..	..	90	890
Salamya, S.	78·90	4,200	2·60	”	..	..	530	1,500
Salamya, N.	78·70	3,400	2·70	”	..	..	600	400
		12,400					1,220	2,790

LIST OF BASINS IN UPPER EGYPT—*continued.*

Name of Basin	R.L. Full Irrigation Level	Area in acres	Mean Renting Value in £	Province	Acres of Flood and Summer Crops, 1898			
					Sugar-cane	Cotton	Summer Sorghum	Flood Sorghum
Bayadia System—right bank of the Nile.								
Gabbana . .	78·30	700	2·60	Kena	..	..	100	90
Hibêl, E. . .	78·15	800	2·80	„	10	..	150	30
Megallabia Enclosure	..	500	2·80	„	30	..	..	80
Hibêl, W. .	77·90	800	2·80	„	10	..	..	160
Gezira Awamia .	77·90	600	3·50	„	40	..	..	20
Karnak, E. . .	77·65	1,100	2·90	„	..	..	200	80
Karnak, W. .	77·40	2,500	3·50	„	250	..	150	160
Ashî . . .	77·00	12,800	2·90	„	40	..	1,250	530
		19,800			380		1,850	1,150
Shanhûria System—right bank of the Nile.								
Damamîl . .	76·15	2,000	2·40	Kena	..	..	210	120
Higâza . . .	75·50	4,500	3·00	„	10	..	750	150
Maärri . . .	75·70	2,100	2·80	„	20	..	..	130
Geziret Mitera .	75·70	700	3·00	„	20	..	..	400
Kûs Farresh . .	75·35	2,600	2·80	„	20	..	..	70
Kift, E. . . .	75·30	9,800	3·00	„	5	..	1,850	350
Kift, W. . . .	75·15	8,200	2·90	„	5	..	60	150
Binûd . . .	74·10	11,700	3·10	„	20	..	1,200	260
Gebelan . . .	73·70	3,500	3·10	„	5	..	650	30
Geziret Humidat .	73·70	900	3·80	„	5	..	..	170
		46,000			110		4,720	1,830
Gilâsi System—right bank of the Nile.								
Makhadma . .	73·40	3,800	2·80	Kena	5	..	350	150
Kinawia . . .	72·20	700	3·00	„	5	..	50	120
Aulâd Âmr . .	72·50	1,700	2·60	„	10	..	30	10
Tawabia . . .	72·20	1,300	2·90	„	..	..	40	20
Abu Diâb . .	71·80	2,000	3·00	„	80	..	90	160
Higârat Enclosure .	..	2,900	2·90	„	80	..	80	350
Samatha . . .	71·50	7,600	2·90	„	10	..	150	90
Gimmêza . .	71·30	3,900	3·10	„	20	..	420	600
Dishna . . .	70·90	11,500	3·10	„	90	..	850	450
Hamad . . .	70·60	18,200	3·30	„	170	..	680	300
Gezeret Salamya, &c.	69·10	9,800	3·80	„	1,110	..	380	..
		63,400			1,580		3,120	2,250

LIST OF BASINS IN UPPER EGYPT—*continued.*

Name of Basin	R.L. Full Irrigation Level	Area in acres	Mean Renting Value in £	Province	Acres of Flood and Summer Crops, 1898			
					Sugar-cane	Cotton	Summer Sorghum	Flood Sorghum
Khyâm System—right bank of the Nile.								
Balabish . . .	67·15	4,600	2·60	Sohag	90	..	150	1,100
Khyâm . . .	67·00	7,000	3·20	"	50	..	..	1,150
Mazata . . .	66·20	7,300	3·20	"	50	..	150	100
Aulad Yehya . .	65·20	5,700	3·00	"	..	..	200	1,150
		24,600			190		500	3,500
Akhmîm System—right bank of the Nile.								
Akhmîm . . .	62·20	7,300	3·50	Sohag	5	..	360	260
Sawâma . . .	61·20	3,900	3·40	"	30	..	580	900
Sawâma Enclosure .	61·20	400	3·50	"	10	..	100	140
Sakulta . . .	61·10	3,900	3·30	"	..	..	20	30
Kitkata . . .	60·35	4,700	3·40	"	20	..	70	590
Galawya . . .	59·60	2,400	3·30	"	10	..	20	980
Galawya Enclosure .	..	400	3·30	"	5	..	..	950
		23,000			80		1,150	3,850
Khazindaria System—right bank of the Nile.								
Nawawra, W. . .	58·20	1,900	3·20	Assiout	..	..	60	100
Nawawra, E. . .	58·50		3·20	"	..	..	150	500
Kaw, W. . .	57·10	1,900	3·20	"	..	..	450	300
Kaw, E. . .	57·50							
Akal and Islands .	57·30	4,300	3·20	"	..	..	10	420
Badari, E. . .	56·20	6,000	3·50	"	..	..	1,700	300
Badari, W. . .	56·20	3,500	3·20	"	10	..	..	..
Hassan Derwesh Sahil . .	..	5,100	3·30	"	50	..	..	300
Sahil . . .	55·50	10,600	3·60	"	30	..	2,300	250
Ghoraib . . .	54·40	700	3·00	"	50	60	30	100
		34,000			140	60	4,700	2,270

LIST OF BASINS IN UPPER EGYPT—*continued.*

Name of Basin	R.L. Full Irrigation Level	Area in acres	Mean Renting Value in £	Province	Acres of Flood and Summer Crops, 1898			
					Sugar-cane	Cotton	Summer Sorghum	Flood Sorghum
Abnûb System—right bank of the Nile.								
Masâra . . .	53·00	4,700	3·30	Assiout	10	..	1,500	600
Beni Murr . .	52·25	4,800	3·30	"	..	..	10	700
Hammâm . .	51·50	4,800	3·40	"	..	..	1,000	..
Gharbia . .	52·00	3,300	3·30	"	..	..	20	600
Sawâlim . . .	51·25	10,000	3·50	"	..	..	2,000	200
Beni Mohamed Enclosure . .	50·60	2,600	3·40	"	..	..	100	..
Maäbda . . .	50·40	4,200	3·50	"	..	..	800	..
Maäbda Enclosure .	50·00	1,400	3·40	"	..	..	..	100
		38,800			10		5,430	2,200
Right Minia System—right bank of the Nile.								
Basins and Enclosures . . .	..	14,600	3·30	Minia	4,100	350	550	500
Right Beni-Suef System—right bank of the Nile.								
Basins and Enclosures . . .	..	1,200	2·60	Beni-Suef	30	20	30	200
Right Geeza System—right bank of the Nile.								
Masgid Musa and Sol	24·80	5,000	3·30	Geeza	10	..	100	2,940
Atfia and Kudya .	23·70	4,000	3·40	"	40	20	540	2,960
Iskar and Saff. .	23·10	800	3·30	"	..	..	60	490
Afwaz and Hassar .	22·20	2,300	3·30	"	..	60	310	90
Minia and Shorafa .	21·50	4,300	3·50	"	10	70	350	..
Kafr Elu . .	20·40	6,500	3·50	"	180	30	280	120
Helwan and Maäsra	20·00	600	4·00	"	..	..	20	..
Basatîn . . .	18·90	1,900	4·00	"	20	20	220	10
		25,400			260	200	1,880	6,610

The following list gives the names of the basin canals of Upper Egypt, their bed widths at their heads, the reduced levels of their beds at their heads, and the corresponding gauge readings referred to mean low water of the Nile.

List of Basin Canals in Upper Egypt.

Name of Canal	Bed at Head			Province	Systems served
	Width, metres	R.L., metres	Gauge, metres		
Left Bank of the Nile.					
Banbân	4	87·56	3·20	Assuân	Banbân.
Ramâdi	18	81·66	. .	„	Ramâdi.
Um Ads	7	77·30	. .	Kena	„ and Asfûn.
Asfûn	12	75·76	. .	„	Asfûn.
Fadalia	11	73·00	3·90	„	Fadilia.
Tukh-Der	12	70·30	. .	„	Sahil Farshût.
Marashda	9	67·87	. .	„	„
Rannân	18	66·64	3·20	„	„
Dumrania	16	64·11	. .	„	„
Rashwania	18	63·46	3·50	„	„ and Kasra.
Kasra	21	61·04	3·40	Girga	Kasra, Girgawia, &c
Zarzuria	17	61·40	. .	„	„ „
Utmanya Minor	8	62·38	. .	„	„ „
Ambarya Minor	5	59·92	. .	„	„ „
Girgawia	18	59·50	2·70	„	„ „
Beni Hillâl	6	57·72	. .	„	„ „
Sohagia	70	56·40	1·80	„	Sohagia, &c.
Tahta	15	56·34	1·80	„	„
Kaw	9	55·80	. .	„	„
Shattûra	9	53·60	. .	„	„
Kharafsha	10	54·50	. .	„	„
Ibrahimia	50	42·30	−2·75	Assiout	Sohagia and Yusûfi.
Waladia	4	48·50	. .	„	Waladia.
Beni Hussein	4	48·06	. .	„	„
Masara	5	45·60	From the Ibrahimia Canal	„	„
Kharfa	2	44·90		„	„
Muharrak	5	46·00		„	Sohagia Delgawi.
Kuseya	3	44·50		„	„
Delgawi	6	43·50		„	„
Sabbakha	25	38·74		Minia	Right Yusuf.
Etsa	10·5	34·10		„	„
Abubakkara	20	33·00		„	„
Sultani	15	27·65		Beni-Suef	„
Nina	7	27·25	Ibrahimia	„	„
Nuêra	8	27·00		„	„
Bababshîn	15	26·00	. .	„	„
Magnûna	10	24·50	. .	„	„
Beni Khudêr	3	24·80	. .	„	„
Zawia	8	22·66	. .	„	Rikka.

LIST OF BASIN CANALS IN UPPER EGYPT—*continued.*

Name of Canal	Bed at Head			Province	Systems served
	Width, metres	R.L., metres	Gauge, metres		
Left bank of the Nile—continued.					
Girza	20	19.90	..	Geeza	Left Geeza.
Geeza	16	19.40	..	,,	,,
Zummur	6	14.70	..	,,	,,
Right Bank of the Nile.					
Khattara	3	89.90	..	Assuân	Right Assuân.
Darau	3	87.78	..	,,	,,
Selwa	3	85.00	..	,,	,,
Ridisia	3	83.20	..	,,	,,
Killabia	10	77.84	4.00	Kena	Killabia.
Maäla	7	75.50	..	,,	,,
Karnak Minor	4	74.82	..	,,	Bayâdia.
Hibel Minor	4	74.82	..	,,	,,
Bayadia	15	72.90	3.70	,,	,,
Higaza Minor	5	72.32	..	,,	Shanhûria.
Kus Minor	7	72.32	..	,,	,,
Shanhûria	16	70.90	3.20	,,	,,
Sheikhia	6	71.60	..	,,	,,
Aulâd Âmr Minor	4	69.84	..	,,	Gilasi.
Gilâsi	15	68.40	..	,,	,,
Samata	10	68.27	..	,,	,,
Tarîf	10	65.27	..	,,	Khyâm.
Hawîs	13	63.90	..	Sohag	,,
Lahaiwia	10	59.40	..	,,	Akhmîm.
Salamûni Minor	5	59.22	..	,,	,,
Isawia	8	57.30	..	,,	,,
Gebel Harîdi	7	56.22	..	,,	Khazindaria.
Khazindaria	18	52.50	2.70	Assiout	,,
Hassan Derwesh	7	51.42	..	,,	,,
Shamia	7	52.42	..	,,	,,
Maäna	15	48.50	..	,,	Abnûb.
Alibey	8	47.63	..	,,	,,
Maäbda	5	46.85	..	,,	,,
Dêr Kuseir	2	44.20	..	,,	Assiout, R.
Birsha	1.5	41.20	..	,,	,,
Shekh Tamai	1.5	39.00	..	Minia	Minia, R.
Sawada	2.5	37.75	..	,,	,,
Zawiet Gidâmi	1.5	30.75	..	,,	,,
Gayâda	1.0	28.80	..	Beni-Suef	Beni-Suef, R.
Bayâd	2.0	26.60	..	,,	,,
Khasshâb	10	21.90	3.00	Geeza	Geeza, R.

If it is required to be known what depth of water may be expected at any canal head during flood, the following facts should be borne in mind :—

For any given gauge at Assuân in flood :—

1. The Kena province gauges will be about 50 centimetres higher, as the river in this province has a slight slope.

2. In the early stages of the flood, when all the basin canals are freely open and discharging full supplies,

Sohag province will be	70	centimetres lower
Assiout "	1·00	metre lower
Minia "	1·00	"
Beni-Suef "	1·20	"
Geeza "	1·20 to 1·50	"

3. Early in October, when the basins are full, the gauges in the above five provinces will not differ much from those at Assuân.

4. Late in October, when the basins are discharging fully back into the Nile, Sohag will be 20 centimetres higher, Assiout 30 higher, and Geeza 70 centimetres higher. Moreover the Nile in an ordinary flood travels at the rate of about 150 kilometres per day, and takes three days to reach Sohag, four Assiout, and six Geeza province.

If, therefore, it is required to be known what depth of water may be expected in the Sohagia and Ibrahimia Canals when the Assuân gauge is 7·5 metres on the 10th September, referring to the table on page 102, it will be seen that the gauges of the heads of these two canals are 1·80 metre, and − 2·75 metres respectively. Consequently on the 13th September the Sohag gauge will be (7·5 − ·7 or) 6·8 metres, and the depth of water in the Sohagia Canal (6·8 − 1·8 or) 5·0 metres. Similarly, on the 14th September the Assiout gauge will be (7·5 − 1·0 or) 6·5 metres, and the depth of water in the Ibrahimia Canal (6·5 + 2·75) or 9·25 metres.

On the advice of Mr. Webb, and with the aid of Messrs. Webb and Verschoyle, I have tabulated the interesting information given in the tables on pages 109 and 110, about the filling and emptying of the basins from 1884 to 1897. By comparing these dates with the Nile gauges of the corresponding years, and applying them to any particular year under consideration, a valuable guide will always be to hand.

The comparative importance of the different seasons has been given on page 17, but Upper Egypt is given there as a whole, and the flood and perennially irrigated tracts have not been separated. I now separate the flood irrigated tracts and give them by themselves.

SUMMER CROPS.

	acres.			
Sugar-cane	20,000 at	£16	=	£320,000
Cotton	13,000	14	=	177,500
Melons, &c.	7,500	10	=	75,000
Summer sorghum	135,000	6	=	810,000
	172,500 at	£ 8	=	£1,382,500

FLOOD CROPS.

Date trees . .	3,450,000 trees	=	£1,040,000
Flood sorghum . .	260,000 acres at £4	=	1,040,000
	260,000 acres	=	£2,080,000

WINTER CROPS.

	acres.			
Wheat	515,000 at	£5	=	£2,655,000
Beans	410,000	4·5	=	1,875,000
Clover	290,000		=	1,330,000
Barley	220,000		=	795,000
Lentils	140,000	3·0	=	420,000
Flax	1,000	8	=	8,000
Onions	15,000	10	=	150,000
Vetches, &c.	115,000	2·50	=	290,000
	1,706,000 at £4		=	£7,523,000
Total area	1,732,000 at £6·30		=	£10,985,500

It will be noticed that 10 per cent. of the area is under summer crops, 15 per cent. under flood crops, and 95 per cent. under winter crops.

If this tract were under perennial irrigation of a fully developed type it would have:—

50 per cent. of its area, or 866,000 acres, under summer crops at £8 per acre . .	=	£6,928,000
40 per cent. of its area, or 693,000 acres, under flood crops at £4 per acre . . .	=	2,770,000
60 per cent. of its area, or 1,039,000 acres, under winter crops at £3·8 per acre .	=	3,955,000
Or the whole 1,732,000 acres at £8 per acre, or		£13,653,000

Since the same area under flood irrigation yields 10,985.500*l.*; there would be a gain of 2,700,000*l.* per annum in gross yield.

The summer irrigation is performed by 5365 water-wheels on the Nile and on canals; by 74 stationary engines with a joint horse-power of 3500; by 81 portable engines with a joint horse-power of 890; and by 17,340 water-wheels on wells in the basins. There is also an almost unlimited number of "shadoofs" worked by manual labour.

The number of masonry regulators is 490; of escapes 102; of syphons 40. The kilometres of basin canals are 3348; of basin drains 313; of basin banks 2281; and of Nile banks 1409.

The earthwork maintenance costs 150,000*l.* per annum; the masonry

works maintenance 20,000*l.*; the flood protection 2000*l.* The total cost of maintenance is 172,000*l.* As the number of acres under flood irrigation is 1,732,000, the cost of maintenance per acre is ·10*l.* per annum.

The prime cost of all these works may be put down approximately as 5,200,000*l.*, or 3*l.* per acre on 1,732,000 acres.

It has been stated that the gross yield of the 1,732,000 acres under flood irrigation is 10,985,000*l.* This sum may be subdivided as follows :—

Class I.

40,000 acres	at £14	=	£560,000
140,000 "	12	=	1,680,000
250,000 "	8	=	2,000,000
1,000,000 "	6	=	6,000,000
180,000 "	3	=	540,000
122,000 "	1·5	=	205,000
1,732,000 acres	at £6·3	=	£10,985,000

Much of the irrigation is very indifferent and needs considerable remodelling on the broad lines laid down by Colonel Ross. If such were done and the fertilising waters of the Nile flood utilised to their utmost, and the subsoil water irrigation developed on the same lines on which we see so much progress being made to-day, the final results would be :—

100,000 acres	at £14	=	£1,400,000
310,000 "	12	=	3,720,000
1,000,000 "	7	=	7,000,000
200,000 "	6	=	1,200,000
122,000 "	3	=	370,000
1,732,000 acres	at £8	=	£13,690,000

Or a gain of 2,700,000*l.* per annum. This could be accomplished without any additional discharge in the Nile during summer.

Sabri bey, Inspector of the Fourth Circle, has sent me, as this book is passing through the press, the following information about the "shadoofs" in Kena and Nubia. The number of "shadoofs" on the Nile in flood time is 16,000, in winter 6000, and in summer 2600. The number of "shadoofs" inside the basins is in winter 5000, and in summer 3000. Half of these are in Nubia and half in Kena. For the Girga province, Sidky bey estimates 1700 "shadoofs" on the Nile in flood, and 2900 on the basin canals in flood.

During the preparation of the "Report on Perennial Irrigation and Flood Protection," I calculated the gauges which might be expected at Cairo if basin irrigation were entirely abolished in Upper Egypt and its place taken by perennial irrigation. The table on page 107 shows how the calculation was made for one year. I may remark here that the column

TABLE III.

PROBABLE CAIRO GAUGES CORRESPONDING TO ASSUÂN GAUGES IF BASIN IRRIGATION WERE CHANGED INTO PERENNIAL IRRIGATION.

1874. Cubic metres per second.

Date at Assuân	Gauges at Assuân	Discharges at Assuân	Perennial Water Consumption, Assuân to Cairo, Calculated	Trough of Nile, Assuân to Cairo, Calculated	Resulting Discharge at Cairo, Calculated	Corresponding Gauges at Cairo	Date at Cairo
Aug. 5 .	6·9	7600	−1020	−1000	5580	5·8	10th Aug.
„ 10 .	7·4	8600	„	„	6580	6·4	15th „
„ 15 .	8·5	11500	„	„	9480	7·8	20th „
„ 20 .	8·6	11800	„	„	9780	7·9	25th „
„ 25 .	8·7	12100	„	„	10080	8·1	31st „
„ 31 .	8·7	12100	„	„	10080	8·2	5th Sept.
Sept. 5 .	9·0	12800	„	„	10780	8·3	10th „
„ 10 .	8·8	11800	„	0	10780	8·4	15th „
„ 15 .	8·7	11500	„	+500	10980	8·5	20th „
„ 20 .	8·4	10600	„	„	10080	8·2	25th „
„ 25 .	8·4	10600	„	„	10080	8·2	30th „
„ 30 .	8·2	10050	„	„	9430	7·9	5th Oct.
Oct. 5 .	7·9	9300	„	„	8780	7·6	10th „
„ 10 .	7·6	8600	„	+700	8280	7·4	15th „
„ 15 .	7·2	7800	„	„	7480	7·0	20th „
„ 20 .	6·6	6600	„	„	6280	6·3	25th „
„ 25 .	6·2	6000	„	„	5680	5·9	31st „
„ 31 .	5·6	5100	„	„	4780	5·3	5th Nov.
Nov. 5 .	5·2	4500	„	„	4180	4·3	10th „

TABLE IV.

COMPARATIVE GAUGES AT ASSUÂN AND CAIRO CORRESPONDING TO BASIN AND PERENNIAL IRRIGATION.

Date	1874			1878			1892			1877		
	Assuân	Cairo with Basin Irrigation, Actual	Cairo with Perennial Irrigation, Calculated	Assuân	Cairo with Basin Irrigation, Actual	Cairo with Perennial Irrigation, Calculated	Assuân	Cairo with Basin Irrigation, Actual	Cairo with Perennial Irrigation, Calculated	Assuân	Cairo with Basin Irrigation, Actual	Cairo with Perennial Irrigation, Calculated
Aug. 5	6·9	..	..	5·6	..	..	6·3	..	..	4·9	..	..
,, 10	7·4	6·5	5·8	5·3	4·9	4·4	6·8	5·3	5·1	5·4	4·0	3·9
,, 15	8·5	6·9	6·4	7·2	5·4	5·2	6·7	5·8	5·8	5·8	4·7	4·6
,, 20	8·6	7·3	7·8	7·5	6·0	6·3	7·4	5·4	6·2	6·4	4·6	5·0
,, 25	8·7	7·5	7·9	8·1	6·3	6·5	8·3	5·8	6·5	6·1	5·3	5·5
,, 31	8·7	7·6	8·1	7·6	6·6	7·2	8·3	6·6	7·7	6·2	5·3	5·6
Sept. 5	9·0	7·7	8·2	8·1	6·5	7·5	8·6	6·9	7·7	6·3	5·2	5·2
,, 10	8·8	8·0	8·3	8·5	6·8	7·5	8·8	7·1	8·0	6·1	5·3	5·3
,, 15	8·7	8·2	8·4	8·9	7·2	8·0	8·8	7·5	8·3	6·0	5·2	5·5
,, 20	8·4	8·3	8·5	8·9	7·6	8·5	8·9	7·9	8·3	6·0	5·2	5·4
,, 25	8·4	8·4	8·2	9·0	7·9	8·5	8·6	8·1	8·4	6·3	5·1	5·4
,, 30	8·2	8·4	8·2	9·1	8·2	8·5	8·4	8·3	8·4	6·1	5·3	5·6
Oct. 5	7·9	8·7	7·9	8·9	8·4	8·6	8·2	8·4	8·3	5·6	5·2	5·4
,, 10	7·6	8·5	7·6	8·5	8·7	8·6	7·8	8·3	8·1	5·2	5·0	5·0
,, 15	7·2	8·3	7·4	7·9	8·4	8·4	7·4	8·1	7·7	4·9	4·9	4·6
,, 20	6·6	8·0	7·0	7·6	8·1	8·0	7·2	7·9	7·2	4·6	4·6	4·4
,, 25	6·2	7·7	6·3	7·4	7·9	7·4	6·8	7·9	7·0	4·5	4·4	4·0
,, 31	5·6	7·0	5·9	6·8	7·7	7·2	6·3	7·8	6·6	4·0	4·2	3·9

* (The Nile breached its banks on the 10th October, 1878, and thus prevented any further rise of the gauge.)

TABLE V.—DATES OF GENERAL DISCHARGE OF BASINS.

Year	Kena Province	Kena to Girga Province	Sohagia Canal closed	Abutig Escape opened	Delgawi Escape opened	Tahana-Shawi opened	Salakusi opened	Koshesha opened	Attwah opened	Komi opened	Rayah Behera opened	Niklai opened	Um Dinar opened	Dêr el tin opened
			Oct.	Oct.	Oct.	Oct.	Oct.	Oct.						
1884	Oct. 10	Oct. 30	27	19	15	19	22	22	..	Oct. 13	..	..	..	..
1885	Sept. 26	„ 1	1	..	..	18	22	11	..	„ 15	..	..	..	..
1886	Oct. 5	„ 5	4	8	13	11	17	left open	..	„ 19	..	Oct. 28	not opened	..
1887	„ 2	„ 2	4	6	5	16	21	7	..	„ 14	Aug. 15	„ 2	Sept. 28	..
1888	Sept. 27	„ 10	28	28	10	15	19	29	..	Sept. 28	Oct. 12	Aug. 27	Oct. 12	..
1889	„ 28	„ 3	6	12	12	17	23	25	..	Oct. 8	„ 29	Oct. 29	not opened	..
1890	Oct. 1	Nov. 1	1	7	25	14	18	16	..	„ 28	Nov. 12	Nov. 20	Nov. 5	..
1891	„ 5	..	10	15	11	13	17	17	Oct. 20	„ 3	„ 3	„ 3	„ 3	Nov. 5
1892	„ 6	Sept. 27	15	16	15	17	22	25	Sept. 29	„ 20	„ 13	„ 14	Oct. 11	Oct. 17
1893	„ 5	Oct. 20	25	15	17	17	19	23	Oct. 30	Sept. 19	„ 5	„ 6	Nov. 10	Nov. 5
1894	„ 5	Sept. 22	24	8	16	18	22	23	„ 26	Oct. 26	„ 9	Oct. 29	Oct. 29	„ 5
1895	„ 4	Oct. 4	12	10	12	13	16	19	„ 27	„ 1	Oct. 28	„ 13	„ 20	„ 5
1896	„ 1	„ 1	11	9	16	17	20	23	„ 25	„ 3	„ 10	„ 18	„ 2	„ 5
1897	„ 1	„ 15 From 1892 Abu Shusha Escape	19	16	17	12	15	20	„ 12	Nov. 20	open through flood	Nov. 3	Nov. 3	not opened

"Trough of the Nile" represents the quantity of water per second which would be consumed in the rising flood to fill the trough of the Nile, and would therefore be deducted from the discharge at Cairo, and which would, on the falling Nile, be added to the discharge at Cairo. The table on page 108 places side by side the recorded Cairo gauges for four typical years with basin irrigation, and the calculated Cairo gauges for the same years with perennial irrigation.

TABLE VI.—DATES OF OPENING OF BASIN CANALS.

Year	Kena Province	Girga Province	Sohagia Head	Delgawi Feeder	Minia Province	Beni-Suef Province	Geeza Province, Left	Khasshab Canal	Closing Rayah Behera Head
	Aug.	Aug.	Aug.	Aug.	Aug.	Aug.	Aug.	Aug.	
1884	10	10	10	..	17	..	19–20	11	Aug. 15
1885	10	6–10	9	8	15	..	11–13	11	not closed
1886	11–13	11–15	15	19	15	..	12–17	9	August
1887	10	9–13	13	10	15	..	13–14	14	Aug. 1
1888	13–15	13–16	14	14	12	12–15	14–17	14	Sept. 1
1889	6–10	12	10	10	15	10	5–14	14	Sept. 4
1890	15	12–15	12	11	14	12	14	15	Aug. 24
1891	15	10–12	10	15	15	11	13–16	16	Aug. 19
1892	11–15	12–15	15	17	15	11–17	6–8	10	Aug. 17
1893	13	15	15	18	16	13	6–15	5	Aug. 26
1894	15	11–15	17	15	15	10	5–15	4	Aug. 26
1895	15	7–15	15	15	15	15	4–15	1	Aug. 21
1896	10	8–13	10	10	10	10	8–10	10	Sept. 13
1897	10	8–10	12	10	10	10	10–12	12	not closed

N.B.—The date fixed by Khedivial decree for the opening of the basin canals is August 10, but when summer sorghum crops exist in the basins, Inspectors of Irrigation have the power to delay the opening to August 15, and in exceptional cases till the crop has been harvested.

Appendix VIII. gives details of existing works in Upper Egypt.

Appendix IX. gives details of water-lifting machines in Upper Egypt.

Appendix XI. gives details of summer and flood crops in the basin tracts of Upper Egypt. For the basins themselves the totals of the systems on pages 93 to 101 are taken, and to them are added the summer and flood crops on the Nile berms.

CHAPTER IV.

BASIN IRRIGATION IN UPPER EGYPT—continued.

PART II.

Selection from Sir Colin Scott-Moncrieff's Report for 1886—Bahr Yusuf basins—Ramadi Canal—Sir Colin Moncrieff's Report for 1887—Bahr Yusuf basins—Colonel Ross' Report for 1891—The Kena basins—The Girga basins—Geeza basins—Mr. E. W. P. Foster's Report for 1893 on the Geeza basins—Major Brown's Report for 1892—Rubble revetments for basin banks—Type sections—Major Brown's Report for 1893—Grass planting and rubble revetments for basin banks—Major Brown's Report for 1894 on the behaviour of the basins in the high flood of 1894—Safe maximum gauges at Cairo—Mr. Wilson's Report for 1896—Summer sorghum and opening of the basins—Escapes on to the Nile—Relief of the basins—Regulation between Fourth and Third Circles—Regulation between Girga Directorate and Fourth Circle—Regulation between Fifth Circle and Girga Directorate—Date of reaching full irrigation level—Discharge of basins south of Assiout—Discharge of the basins north of Assiout—Effect of opening the Koshesha Escape—Most suitable dates for discharge—Water for early and late flood sorghum—Lands on the west of the Bahr Yusuf—Dates of principal events of discharge in the Fourth Circle—Reveting of basin banks with stone—Sir William Garstin's Report for 1896—Summer sorghum—Final decision about opening of basins—Koshesha escape opening—Mr. Webb on the necessity of remodelling the basins west of the Yusuf Canal.

WE have so far considered the theory of basin irrigation. We now turn to its practical working. Selections from the Irrigation Reports of the different years will be our best guide. The first is from Sir Colin Scott-Moncrieff's Report for 1886.

"As the Nile rose slowly in 1886, Captain Brown had no difficulty in regulating the gates at Deirut. In order to apply as much *red water* as possible to the basins west of the Ibrahimieh, the Nina Canal (passing under the Ibrahimieh by a syphon finished in 1884) was worked fully and discharged 20 cubic metres per second after 23rd August. The Magnuna Canal, which leaves the Nile at Beni-Souef, was used for the first time this year since the Ibrahimieh Canal was opened. Its object was to supplement the tail of the Ibrahimieh Canal and to pour rich muddy water into the south-east corner of the Koshesha basin. It discharged 15 cubic metres per second. This basin also received as last year its water direct from the Nile through the Abu Kadiga dam, which was left open, and the cultivators say the results of these measures have been to raise the yield of the Koshesha basin from 4 to 6 ardebs* per acre. It was necessary to protect the breach in the Abu Kadiga basin and to regulate its size. The bed was fixed at reduced level 19·75, that is 7 metres below high flood level in the basins; its width was 20 metres with side slopes of 2 to 1. The forming the banks and protecting them with stone pitching cost 2050*l.* The

* 1 ardeb = 5½ bushels very nearly.

object of these works is to prevent the water from flowing too fast out of the Koshesha basin as the Nile falls, before it has watered the highest parts of the basin. This year when the water surface in the basin stood at level 26·10 on the 19th October, Captain Brown learned that there was no part of the basin unsubmerged. He then opened the upper basins so as to empty them as fast as possible and to produce a wave sufficient to submerge the highest points of Lower Egypt.

Captain Brown has closely studied the means of supplying the great irrigation basins with muddy water fresh from the Nile, and regulation of that water in passing from basin to basin. In conjunction with Abou Saoud Bey, inspector of irrigation in the two southern provinces, it was arranged that the water from Keneh should be passed on to Girgeh 5th October, that simultaneously water in Girgeh and Assiout should be let go northward, that on the 12th the Minieh basins, and on the 16th, the Beni-Souef basins should be opened. The breach in the Abu Kadiga dam fast widened and the basins emptied after the 19th October.

The Ramadi Canal in Esneh, which is one of the most important inundation canals in Egypt, runs for a distance of about 105 kilometres with a head discharge of about 72 cubic metres per second. Like the Ibrahimieh it has no regulating sluices at the head, and the first regulating bridge across it is at Kelh, kilometre 35. The want of an escape channel back to the Nile has long been felt at this point to fill the place of the Deirut escape on the Ibrahimieh. The work was at last begun in 1886, but little was effected save the collection of materials on which 400*l.* were spent. It is being completed in 1887. A regulating bridge was built on the Maalla canal (right bank of the river) at a cost of L.E. 1085, and this canal was prolonged past a stony promontory reaching to the river's edge, so as to take water at a higher level to the basins south of Luxor. This prolongation cost 1041*l.* The Shansuriyah canal (also on the right bank of the Nile) was widened and prolonged west of the town of Keneh at a cost of 5051*l.*"

In the Report for 1887, Sir Colin Scott-Moncrieff writes as follows:—

"In 1883, great importance was attached to the fact that the Ibrahimieh Canal had cut off from their direct source of supply in the Nile the long chain of basins to its west leading from Assiout to Koshesha, a distance of about 260 kilometres, and that these basins were either fed by the Bahr Yusuf, which had lost a good deal of its fertilising mud, or still worse, only one from the other, so that towards the northern end they received almost clear water. Year by year this evil has been diminished. The great Koshesha basin has now for three years received its water supply direct from the Nile through the Abu Khadiga bank, and at its south-east corner by the Magnuna Canal direct from the river. These measures have greatly enriched the lands of this basin. The Bahabshin basin next it to the south will soon, it is to be hoped, draw the Nile water direct through the Selim Pasha syphon, the feeding canal only requires to be enlarged. The Nuera basin next to the Bahabshin received its water for the first time in 1887 direct from the Ibrahimieh Canal by the new Kolussi Canal. Next to the Nuera comes the Nina basin, which since 1884 has drawn its supply direct from the river by the Nina syphon.

Next to the Nina basin comes the large Sultani basin (32,000 acres), which will in future be fed through the Feshn syphon.

Going further south, Captain Brown is hopeful of arranging for filling the Bardanuha Garnusi basin, in Minieh, through a syphon under the Ibrahimieh Canal at Abu Bakara, discovered by him last year. The very existence of this syphon was unknown, as it was completely buried under the earthen banks of the canal. Captain Brown has had it dug out and put in order, and finds it a work of seven semicircular arches of 3 metres span on piers 2·50 metres high. It will be readily adapted to pass off drainage water into the Nile in the same way as the Feshn syphon, but before the basins can be fed through it, an expensive feeder canal must be excavated.

Still further south, the Tanashawi basin was fed for the first time in 1887 direct from the Ibrahimieh, through the long disused Subaka Canal. A new bank was placed across the south end of this basin which will in future prevent its being filled at all from the south. It will be filled henceforth from the Subaka Canal and Bahr Yusuf.

The Ashmunin basin was fed for the first time from the Deirutieh Canal by the new sluices at Kolobba."

In the Report of 1891, Colonel Ross, C.M.G., writes:—

"In the Fifth Circle, the management of the Nile flood was conducted to a successful issue under the direction of the inspector, Abu Saud Bey. In the Ghilasi system where in one season a complete set of regulating bridges had been built where there were none before, the greatest credit is due to the local staff. The regulating planks had been delayed, owing to the difficulty of getting wood, and in this system, they arrived only just in time, in fact rather late. The local district engineer, a young man, deserves great praise for his efforts in working this totally new system, and for the numerous observations he made of the heights attained by the water and the exact heights necessary for full irrigation. In the Sahil Farshut there was great difficulty and even risk of a short supply. The new works, owing to their magnitude, were not finished on the 15th August, and a delay of ten days occurred in opening the Rashwaniyah Canal. This caused great distress to the Kena cultivators who could not sow their flood sorghum. The Girga people in Bardis were deprived of water for ten of the most precious days. The Sahil Farshut was much better managed this year than last, and there were no accidents on the new minor canals which had been fitted with head and tail works. The only hitch that took place was the deprivation of water from the low land below Haw west bridge, owing to the great demand on the Nile berm. The low land channel should have been dammed. The assistant engineer of Farshut worked very hard and was most successful in getting the numerous canals regulated. Owing to the Damraniyah Canal not having been widened, the Samhud basin filled very slowly, and great anxiety was felt on this account. Also on the Nile berm below Naga Hamadi, where the chief engineer of Kena made a great mistake in the levels of the piers of the Hamraniyah syphon, there was difficulty felt.

In the Shanhuriyah Canal berm also, owing to the absence of one of the new regulators, the Qus-Farrash basin had to be raised to its old level, and thus some sorghum was drowned. This flood sorghum was sown by the people too profusely, seeing the new works could not be ready till 1892.

All these hitches are inseparable from so sweeping a change in distribution

as has been made in 1891 with the works incomplete. In 1892 I am certain there will be no hitch.

The delay in opening the Rashwaniyah had a very disastrous moral effect in Girga, and caused some doubt to be felt about the success of the new arrangement for getting water from the Kena province. I heard a man say that he did not think the deposit in Beni-Himel basin was anything like former years, and he argued that the water was "filtered" through the syphon. The upstream of the Beni-Himel east regulator did not rise above 65·00 until after September 23rd. Thus 25 days were lost, as it is only when the water is above 65·00 that this land is irrigated.

In this matter of the delay of opening the Rashwaniyah Canal, the Girga engineers committed the error of not regulating on the Beni-Himel regulator until between September 23rd and 30th.

The water was allowed to race into Bardis basin when a little check would have made it rise to 65·50 without in any way diminishing the income of water from the Kena mudiriyah. The heads of 0·15 and 0·17 are natural and show the large amount of water passing.

Fortunately the good height of the Nile in September overcame all obstacles in the bed of the fine new canal from Kena mudiriyah, and the velocity was such that the holes dug irregularly did not silt in even in the depressed parts in the bed of the canal.

In the Khiyam system there was an enormous supply, as the Tarif syphon canal supply flowed up to high Nile level. The want of regulators, however, caused the water to run rapidly to the lower levels, thus leaving the high land dry, and some of these local high pieces between sorghum fields were not irrigated till the first week of October. The necessary regulators to prevent this rush of the water into the lower levels and out into the Nile by the escape are being made in 1892.

The Gebel-Haridi Canal did not give enough water, owing to the people having sown flood sorghum in the unprotected tracts along its first three kilometres. This will be prevented in future by protecting these old inundated lands. The want of the Nawawrah bank regulator was severely felt, and the dam of stones in its place was not well maintained. The Khizndariyah new works acted well and gave an extraordinarily good supply. An outlet, through the low land of the Badari basin, is much wanted, but it cannot be dug at present. The Khizndariyah Canal silted in greatly, owing to want of an outlet, but the entire canal will be truly dug throughout its length in 1892.

The new escapes all acted well, and the sloping floors were most successful in diminishing the action downstream.

Owing to the high level attained by the flood of 1891, there was no difficulty in filling basins in Gizeh province; on the contrary, preventing them from rising to a dangerous height required considerable management. Musa Bey Ghalib, the chief engineer, was very successful in this; no accident whatever occurred.

The flood being late in falling, the discharge of the basins was not commenced until the 28th October, when the Abu Numras escape in the Shabramant basin was opened. The Nikla, Om Dinar, Rahawi escapes and the Rayyah head sluice were opened for discharge on the 10th to 12th November. On the east the discharge was commenced on the 1st November and finished by the 20th. The quantity of

water stored having been great, and the flood falling slowly, it was not until the 25th November that basins south of Shabramant were all clear of water. Those north of Shabramant were later still in draining.

The Gizeh Canal, constructed in 1891–92, did good work in supplying red water at a high level early in the season, to the Indian corn between the railway and the Nile. The want of more regulators was seriously felt. This is being rectified in 1893 by the construction of one or two.

The area of land reserved for flood sorghum and Indian corn is increasing. As this land is protected from flooding, it is possible to cultivate summer crops. Although the area of cotton is still insignificant, it is steadily increasing. The Gizeh Canal will probably tend to increase the area of perennial cultivation.

It was feared that the delay in completing the discharge might seriously affect the winter crop which was late in being sown, but fortunately it has not done so; the crop has, on the contrary, proved unusually good. No doubt the large quantity of fertilising mud resulting from water remaining on the land for an unusually long time has much to do with this."

Mr. E. W. P. Foster writes in 1893 about basin irrigation as follows:—

"Water was admitted to the west Geeza basins, by way of the Girzeh regulator, on the 15th August; and to the east basins, by way of the Khashab Canal, on the 5th of the same month.

In order to increase the quantity of water discharged into the west basins, the Aguz and Abu Numras escapes were also opened for back flow.

Water was kept out of the Iswid basin until the 18th September. A considerable area of cotton was sown on the higher portions of the basin, and it was to save this crop from destruction that water was not admitted.

This arrangement is exceedingly bad. By delaying opening the basin until so late in the season the land is deprived of red water, which is so necessary for renewing the soil. A continuance of this system for several years would result in this basin, which now produces rich crops, becoming partially sterile. It is distinctly unfair that some 30,000 acres of land should suffer for the sake of rearing a few hundred acres of cotton.

Those who wish to grow cotton can do so after first enclosing the land to be planted. There are many enclosed plots in the Iswid basin in which cotton can now be planted without the risk of being flooded out.

So anxious are owners to grow cotton in this basin that the proprietors of some 12,000 acres have agreed to subscribe upwards of 4000*l.* and to give the necessary area free of cost, to make an enormous bank between the Nile and the lowest part of the basin, extending some 10 kilometres in length. An application has also been made for the erection of large steam pumps to irrigate this area.

To sanction these demands will result in a considerable area of perennial cultivation being added to the already large area in the Delta dependent for irrigation on the limited summer discharge of the river. And if granted, it will be difficult to refuse other similar applications which are certain to follow.

Whether Giseh is to be allowed to participate with the Delta, and undoubtedly to the detriment of the Delta in bad years like 1892, is too large a question to be hastily answered.

But to return to basin irrigation of 1893.

The flood having been a low one, the western basin could not be filled without assistance from the Fourth Circle. When the flood began to fall early in October, the Girzeh regulator was closed on the basin side and the Komi regulator in the Rikka basin partially opened to maintain a sufficiently large discharge, not only to overcome evaporation and absorption, but to add slowly to the rise of water level in basins.

A few days prior to opening the Qoshesha escape for the draining of Middle Egypt basins, Komi regulator was fully opened and a very large discharge poured into Giseh, which proved sufficient to bring all the basins to full irrigation level in succession.

On the east, considerable watchfulness and care were necessary to ensure flooding the high lands. When the flood began to fall at Assouan on the 19th September, Mr. Joseph, fearing that the southernmost basin in the chain would not be flooded, had the regulator in the bank of this basin closed. Full irrigation was thus secured.

The remaining basins being situated at a lower level were subsequently flooded in succession.

The Qoshesha wave helped materially in completing the thorough irrigation of this chain of basins.

When the flood declared itself a low one, orders were issued to enclose all high lands on the Nile berms (which are only topped by ordinary or high floods), with small banks to allow of their being flooded by water stored at a high level in basins.

Mr. Joseph reports that 98,513 cubic metres of earthwork, costing 1478*l.*, were executed in a limited time, which is much to the credit of those concerned.

Thanks to these banks and the Qoshesha wave, there were only 150 acres unirrigated in Giseh. 675 acres had been irrigated by machinery. There were, therefore, 825 acres which did not receive free flow irrigation.

On the west, the discharge of the basins was commenced on the 4th and completed on the 28th November.

On the east it commenced on the 2nd and was completed by the 15th of the same month.

Mr. Joseph states that owing to the improvement of the basin central canal, known as the Libaini, the lower portions of the Iswid basin were drained far more rapidly than in previous years."

In the Report of 1892, Major Brown writes as follows :—

"Considerable lengths of basin banks have now been reveted with stone and planted with grass roots.

The total lengths of banks by provinces is given below.

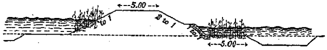
		metres
Esna		Nil
Kena	Rubble revetment	4,140
	Grass planting	Nil
Girga	Rubble revetment	8,735
	Grass planting	10,500
South Asyût	Rubble revetment	15,766
	Grass planting	19,445
North Asyût	Rubble revetment	8,318
	Grass planting	72,207

		metres
Minyâ	Rubble revetment	10,291
	Grass planting	81,804
Beni Suef	Rubble revetment	15,106
	Grass planting	25,540

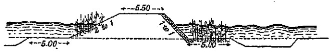
In North Asyût, a length of 8500 metres of the north berm of Beni Rafi cross-bank has been also planted with grass roots and, in addition, also both the inner slopes of the Ibrahimiyah Canal for a length of 35 kilometres between Asyût and Derût. This last is intended to prevent the sides of the canal from being eroded by surface wave action.

This grass planting is still more or less of an experiment which has been made before, but the previous efforts were made by chief engineers under the conviction that it was impossible to make grass grow on basin banks, and therefore a fair trial was not given. Nevertheless, the experiment succeeded on one bank, the Suhag basin cross bank, which was sufficient to show that the grass might be made to grow almost anywhere, as Suhag is as dry as most places in Egypt.

Nº 1



Nº 2



The ideal section of a basin cross-embankment is shown in the above diagrams, the upper section, No. 1, being that of a bank which is exposed to the wash of waves of ordinary size on the side on which the water is shallow; the lower, No. 2, being that of a bank which has deeper water and more formidable waves to resist on one side.

In 1891, in consequence of the excess in the quantity of material that it was found necessary to dredge in the Ibrahimiyah Canal, there were no funds available for the purchase of stone for reveting the slopes of basin banks, and all that it was found possible to do was to build the stone collected the year before. In 1892, as the dredging bill was much less, a large quantity of stone was purchased and stacked on the banks ready to build in 1893."

In the Report for 1893, Major Brown writes again of the basin bank revetments:—

"The inspector of the Fourth Circle in 1893 planted all the berms between the spurs with a new kind of grass found on the islands near Manfalut, and some of this shows signs of growing, though much of it appears to be dead. I think the

experiment with willows was given up too readily, and that it will be advantageous to make a more extended trial with them.

The grass planting on the basin banks cannot be considered a success at present. It is too much at the mercy of the cattle and fellahîn, but, if left undisturbed by them, it would, I believe, succeed. Some of the grass has taken, but it can scarcely be said to take kindly to such dry situations as basin banks are from April to August.

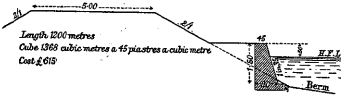
No further grass planting was added in 1893 to that already planted on the basin banks.

In the Fourth Circle the large quantities of stone collected and paid for in 1892 were built on the bank slopes in 1893, and this work paid for at the rate of 6 piastres a cubic metre, the previously existing revetments being also put into repair, for the following expenditure:—

	cubic metres	
First Section Assiout	23,188	£1615
Minia	23,867	1457
Beni Suef	15,916	955
		4027

A retaining wall of coarse masonry of village bricks in mortar made of lime and Nile mud, protected by a good plaster face of ordinary mortar of lime and pounded brick, was built along 1200 metres of the restored Beni Alêg cross-embankment in the Abnub district of Girga Directorate, and along 1400 metres of Hamad crossbank in Kena Province, Fifth Circle.

The Beni Alêg wall has a width at top of 0·45 metre, and an external batter of 1 in 3·5, the interior face, which is buried in the bank, being vertical. The section and cost are given below.



This gives a rate of about 50 piastres* per lineal metre of bank. A dry rubble revetment for the same bank would cost about 25 to 30 piastres a lineal metre, but, where the waves are formidable this latter class of revetment is not so efficient, and requires considerable annual repairs; whereas the wall, if the plaster is of good quality and well applied, requires scarcely any repairs.

In the Fifth Circle, besides the building of the Hamad bank wall, no new basin revetment work was done, the old dry rubble revetment to Hamad longitudinal bank only being repaired.

The section of the Hamad bank revetment wall was the same as that of Beni

* 100 piastres = 1*l*.

Alêg Salibah, but the height was greater. A length of 1400 metres was built for a sum of 1475*l.*

In the Girga Directorate there was spent on dry rubble revetments, both new and repairs :—

In Girga Province	£1463
In Second Section Assiout	1767 "

In the Report for the high flood of 1894, Major Brown writes as follows :—

"As in 1892, it was judged advisable to fully open the Koshesha escape early to avoid the risk of obtaining excessive levels in the basin, which might have endangered the stability of the banks; for, if the Koshesha cross-bank were to breach when the basin was at a high level, the effect on the Ghizah province, and probably on Cairo itself, would be disastrous. A sudden rise in both the Damietta and Rosetta branches would also be caused, which might result in a breach of the Nile bank in Lower Egypt.

The operation of opening the escape extended over six days, ten of the upper gates being let go daily, commencing on the 27th September.

The inspector of irrigation, Fourth Circle, received instructions at the end of September to be prepared to open Dalgawi escape on the 13th October, but to commence lowering the basins between Asyût and Derût from the 5th October, by shutting off their heads, keeping, however, Dalgawi basin full.

It was also arranged that the Fifth Circle and Girga Directorate should commence to discharge on the 5th October, by gradually opening the tail escapes and closing canal heads not already closed, so that all escapes might be fully open and all canal heads closed by the 15th October; with the exception of Araba and Gharizât basins on the west of the Suhagiyah, which were to commence their discharge on the 3rd October, while the Suhagiyah was still high, so that the rate of discharge might not be too rapid and the ground be uncovered more quickly than it could be sown.

But as the fall of the river at Assuân during the first week in October was so slight, it was thought better to telegraph instructions to the director of Girga Directorate to postpone the commencement of the discharge of the basins south of Suhag town to the 7th October, and of those to the north of Suhag until the 8th, and he was further instructed to conduct his discharge very slowly.

On the 8th October, as the Asyût gauge had risen, and the fall at Assuân was but slight, the Fifth Circle and Girga Directorate were telegraphed to stop further opening of escapes until the gauges again began to show a fall; and the Fourth Circle was also warned to be prepared for the postponement of the opening of Dalgawi escape. On the 12th the Fifth Circle was ordered to regulate its discharge so as to keep the reading on the Kasrah Canal head gauge as near as possible to, but not exceeding, R.L. 66·30. Girga Directorate was to regulate its discharge by the Asyût Canal gauge, on which the reading was not to exceed R.L. 52·97. The opening of Dalgawi escape was postponed to the 15th October, the same date as in 1892.

It was thought at this time that it might be possible to keep the Rodah (Cairo) gauge down to 8 metres (i.e. 24½ cubits) and this is equivalent to R.L. 26·85 on the

Wastah gauge. This level was therefore given to the Fourth Circle to work to, and if the reading was lower, advantage was to be taken of it to get rid of some of the Beni Suef basin water. But the opportunity did not occur before the final fall had commenced.

On the 16th the inspector, Fifth Circle, telegraphed that all canal heads were closed and escapes open, with the exception of Samhud basin, where the river was higher than the basin. This escape could not be opened till the 19th October, by which date the river had fallen to 41 centimetres below the basin level. After this its rate of discharge depended on the rate of fall of the river. On the 31st October the inspector telegraphed that the discharge had been completed very satisfactorily, and that the following areas of sorghum and sugar had been protected throughout the flood from inundation :—

Keneh Province	15,000 acres sugar cane
	80,000 " sorghum
Frontier "	16,000 " sorghum

The discharge of the basins in Girga Directorate was satisfactorily completed and, with the exception of the case of Gharbiyah basin, all went smoothly, the levels maintained by the river preventing a too rapid discharge. The date on which the discharge was considered to be completed was not reported, but it was over in good time.

On reaching Cairo, after arranging the general lines on which the discharge was to be conducted, I discussed with Mr. Foster the subject of the maximum level on the Cairo gauge which might be reached without producing more than ordinary difficulties in Lower Egypt, and we came to the conclusion that 8·20 metres ($24\frac{1}{2}\frac{8}{4}$ cubits) was the most desirable level to maintain, as a higher level would produce serious difficulties, and a lower level could only be obtained on the condition that the basin water of Upper Egypt be passed off slowly, and that the flood be proportionately prolonged in Lower Egypt in consequence. I therefore changed the reading on the Wastah gauge, to which the Fourth Circle might raise the river, from R.L. 26·85 to R.L. 26·95; but, on account of the high levels of Kosheshah basin, the inspector of irrigation wisely waited to discharge the Beni Suef basins until the Kosheshah basin level had fallen to R.L. 27·30. Before the basin had reached that level, the Wastah gauge readings had fallen below R.L. 26·95.

The discharge operations of Middle Egypt are more complicated and interesting than those of the basins further south. Fortunately we are better informed as to what takes place in the Fourth Circle than elsewhere in Upper Egypt. Mr. Webb has submitted a very complete report of the flood operations of 1894 from beginning to end. By well considered arrangements and energetic supervision, he conducted the season's flood operations most successfully. The printed Flood Report of 1892 was useful in showing what to expect as the result of the different incidents of the discharge. Dalgawi escape being opened on the same date as in 1892, it was interesting to note if the effect produced by it and the successive operations following it were the same in time and magnitude as in 1892. Mr. Webb has given several tables making this comparison, which I take from his Report, from which also much that follows is taken verbatim.

The following table shows the dates on which the maximum effect of the Asyût and Minia basin discharge was felt at the different points affected.

Localities	Dates in October	
	1892	1894
Bahr Yusûf at Dalgawi Escape	18th to 19th	18th to 19th
" opposite cross-bank Tahnashawi	20th	19th to 20th
" " " Menqatîn	20th to 21st	20th
" " " Garnusi	22nd	23rd
" " " Kom el Saaydah	23rd to 25th	24th
" " " Nuêrah	23rd to 26th	24th to 25th
" above Lahûn Bridge	26th to 29th	26th to 27th
Kosheshah Basin above the Escape	25th to 29th	26th to 28th
Nile at Wastah	26th to 27th	24th to 26th
Nile at Cairo	26th to 29th	26th to 28th

The effect of the Bahr Yusuf flood, due to the discharge of the basins, was to raise the gauge readings by the following amounts in metres:—

Lahûn		Kosheshah Escape		Wastah		Cairo (Rodah)	
1892	1894	1892	1894	1892	1894	1892	1894
0·27	0·34	0·25	0·30	0·16	0·09	0·12	0·12

From the date of the opening of Dalgawi escape on the 15th October, the commencement and culmination of the effect, as shown by levels, reached the points named after the intervals given in the table below:—

—	Lahûn		Kosheshah Escape		Cairo	
	1892	1894	1892	1894	1892	1894
	days	days	days	days	days	days
Commencement of effect	8	8	8	8	9	8
Maximum effect	13	11	14	12	12	12

From these records it will be possible in any future year of similar flood to predict what effect, and when it may be expected, and we may conclude that eight or nine days after the Dalgawi escape is opened the Cairo gauge will rise about 12 centimetres, and continue high till the 12th day, after which it will continue to fall.

The combined effect of the discharge of Asyût and Minia basins, and of the slow rate of fall in the river above the point affected by the Kosheshah escape discharge, caused the level of Kosheshah basin at the escape to rise to R.L. 27·52 by the 27th October, exceeding the maximum level of 1892 by 3 centimetres, and

that of full irrigation by 77 centimetres. The basin level at Lahûn reached R.L. 27·75, that is, 10 centimetres higher than the maximum of 1892.

Such high levels caused severe action on the banks separating the basin from the perennial cultivation of Beni Suef. These banks were thoroughly well protected.

At one point where danger was not expected, a breach would have occurred had it not been for the prompt action and energy displayed by Mr. E. E. P. Bramall of Beni Suef, who directed his stone boats to the spot in danger, and himself superintended its protection. A large area of valuable crop was thereby saved from inundation.

There is a further subject about the irrigation of Middle Egypt, on which Mr. Webb gives some definite information, which has not been given before and which will be useful to record for future guidance. I therefore give the following extract from his report.

'At the time of the discharge of the Asyût and Minia basins there is always a considerable area of land on the Bahr Yusuf, principally on the western bank, which has not yet been irrigated; this year the area was approximately 17,600 acres.

'In order to inundate this area, it is necessary to produce a sudden rise in the level of the Bahr Yusuf, by bringing the discharge of some of the Minia basins on the top of the flood caused by the opening of the Asyût basins.

'The following table shows the reduced levels of the gauges of the Bahr Yusuf at the principal point concerned.

—		Asyût Province	Minia Province.			Beni Suef Province
		Escape Dalgawi	Bridge Zanuba	Ali Pasha Hilmy's Engine	Bridge Gamal	Bridge Mazurah
Before commencement of discharge	*a*	44·85	39·25	36·80	33·69	31·26
Maximum produced at time of discharge	*b*	45·54	39·99	37·47	34·41	32·41
Working gauges aimed at for inundation of all lands . .	*c*	..	39·95	37·45	34·40	32·45

'By comparing (*a*) and (*c*) it will be seen that it was necessary to produce a sudden rise of

'0·70 metre at Bridge Zanubah, which is near the S. limit of Minia Province.

'0·65 at Ali Pasha Hilmy's engine, Minia.

'0·71 at Bridge Gamal.

'1·19 at Bridge Mazurah, near the boundary of Minia and Beni Suef provinces.

'This rise has to be produced by opening the Dalgawi escape in the Asyût Province, and the Tahnashawi and Garnusi escapes in the Minia Province, and as these escapes never give sufficient rise, the rest has to be made up by making cuts in the longitudinal bank of the basins into the Bahr Yusuf.

'By comparing (*b*) and (*c*) it will be seen that the levels actually attained agree

closely with those which are aimed at; considering the difficulty of judging what the effect of a cut in an earthen bank may be, it is astonishing how close the agreement is, but it is really due to the experience gained from the results of former years.'

It is, I think, the general opinion of Lower Egypt irrigation officers, that, if possible, the Cairo gauge reading should not be allowed to exceed 8·20 metres (or $24\frac{13}{24}$ cubits); but this opinion is not universal, and Mr. Willcocks considers it would be better to boldly let loose the Upper Egypt basin water, so as to get rid of it early, even though it produced levels exceeding 8·35 metres (25 cubits). He would let it rise to 8·60 metres ($25\frac{1}{2}$ cubits), without hesitation, early in October. The long continuance of the flood at high levels produces much damage by infiltration behind the Nile banks, and the question is a choice of evils; extreme high levels producing danger of breaches, and prolonged high levels, though not extreme ones, producing much damage by filtration. The latter evil is certain to take place, but the former may, perhaps, be guarded against and avoided. Still the damage, which would be far-reaching in the case of a breach, would be many times more considerable than the damage due to infiltration, which is limited to comparatively narrow strips of country inside the Nile banks.

On account of these considerations the level of 8·20 metres was decided on as the level which it would be as well to reach but not to surpass, if the basin discharge could be so controlled as to produce this level. This level was, however, surpassed for five days, but not by much, the maximum excess being 8 centimetres.

Another question was raised as to the most suitable time for discharging the basins of the Fifth Circle and Girga Directorate, it being desirable to get their water past Cairo before the Middle Egypt water reaches Kosheshah. It was suggested that the Upper Egypt basins were not discharged early enough, and that the discharge of the Fifth Circle might have commenced on the 25th September. This date, however, is too early in the interests of the Fifth Circle provinces, as sowing, after the retreat of the water, would in such a case have had to be begun before the favourable season. There would, however, not be much objection to beginning on the 1st October, though the 5th is preferable in the interest of the basin land itself. But no advantage to Lower Egypt would have been gained by so early a commencement as that suggested; for, by beginning the discharge on the 5th October and proceeding with it slowly at first, as was done in 1892 and 1894, all the water that could have been got rid of by the basins was discharged before the 20th October, and the rate for the rest of the discharge depended on the rate of the fall of the river, as the tail escapes of basin chains could not discharge faster than they did for want of head. The result of commencing the discharge earlier would have been to have raised the levels at Cairo during the first ten days of October, to have lowered them for the second decade, and to have left them the same during the third decade. As the highest levels of the flood at Cairo occurred between the 23rd and the 29th October, there would then have been no advantage gained by advancing the date for commencing the discharge of the basins south of Asyût. The variant, which determines whether the Cairo gauge will rise high or not when the basin discharge of Middle Egypt is added to the river, is the rate at which

the river discharge, where it enters Egypt, decreases. The effect of the Middle Egypt discharge, controlled as it was in 1892 and 1894, was not a variant, but badly managed, might easily become a serious one. After a certain stage of the discharge, which is reached before the 20th October, the Upper Egypt basins also, since they fall with the river, become one with the river, and depend for their further emptying upon its levels as determined by the discharge passing the First Cataract.

From the above considerations I conclude that no relief to Lower Egypt would be experienced by making Upper Egypt commence its discharge earlier than the date which is most favourable for the sowing: namely, the 5th October.

Still, whatever improvements might have been introduced in the manner of handling the basins, the results of the flood of 1894 were very beneficial to Upper Egypt, due to the abundance of the water, and the fertilising matter carried by it. The inundation water was got rid of, in spite of the prolonged maintenance of high levels in the river, in time for the seed to be sown during the favourable season, and no complaints of delay in running off the water were received. The absence of such complaints, which were common in former years, is due to the attention that has been paid to the clearance of the drainage lines, which carry off the last of the basin water from the lowest lying lands.

The result was thus satisfactory in Upper Egypt without prejudice to the interests of Lower Egypt, where there were no accidents, and little damage of any sort except that arising from the inevitable infiltration over a narrow strip within the river banks along both branches of the Nile. It was not until the flood subsided that it was possible to get rid of the greater part of this infiltration water."

The next selection is from the Report of Mr. W. J. Wilson, on the Basin Irrigation of 1896.

"Except that the river rose slowly in the first half of August, the flood was very favourable, and the filling of the basins was carried out without any difficulty. The discharge of the northern basins was delayed by the rise of the river in November.

The 10th of August was fixed by decree of the Council of Ministers for opening the basins. A few basins, in which there were no summer sorghum crops, were opened before this date, but it was necessary to postpone the opening of some basins till the 15th idem, in order to avoid damaging the crops in them.

The summer sorghum is grown chiefly in the low ground bordering the desert, where the saturation level is higher than it is near the river, and the water has consequently to be lifted to a less height. Considerable labour is expended on irrigating and manuring the crop, and, as it yields an excellent outturn, its cultivation should be encouraged as far as possible. In the northern provinces it generally succeeds clover and beans, which are cut early, and it is harvested earlier than in the Kena and the Assuân provinces, where there is very little clover, and the sorghum follows lentils.

The general opinion of the landowners and cultivators appears to be that the 15th August is the best date for opening the basins. The inspectors in Upper Egypt are agreed that the 10th August is the earliest date on which they should be opened, and in this opinion I concur. It has been decided to adhere to this date, and that inspectors will postpone the opening of any basins in which summer sorghum crops exist in low ground until the crops are harvested.

In the Fourth Circle and Girga Directorate nearly all the basins were opened on the 10th August, but some of the feeder canals were opened gradually and were not fully open to the 14th idem. In the Fifth Circle also most of the basins were opened on the 10th August; but it was necessary to regulate the supply so as to avoid drowning sorghum. The northern Esna, Asfûn and Wadi El-Ginn basins in the Ramadi system, and the eastern Hibel and eastern Karnak basins in the Bayyadiyah system, were nearly covered with summer sorghum and were not opened till the 15th August. Water did not enter the canals feeding some of the southern basins before the 12th and 15th August, owing to the low level of the river.

Some of the escapes on to the river, which would not stand reverse pressure, were strengthened during the year so as to admit of their being kept closed until the date fixed for opening the basins; but, owing to the slow rise of the Nile, comparatively little pressure was brought upon them.

In the early part of a flood an escape on to the Nile should be used as far as possible to feed the basins. In the case of an independent system of basins with its own feeder and escape, and unconnected with any other system, this is an easy matter, as the escape can be left open and the regulator in the bank to the south of the escape can be closed. The water entering the system by its proper feeder will be kept in the southern basins, and the most northern basin will be fed by red water through its escape. If the flood is high the tail basin may be almost filled in this way: if the flood is low it will have to be brought to full irrigation level from the southern basins during time of discharge, but it will have benefited by the silt received through the escape, while the southern basins will have gained by the water of the feeder canal having been retained in them.

In some of the more complicated systems of basins it is not so easy to take advantage of the escapes as feeders, but this can generally be done to some extent. The Abutig escape, for instance, is opened two days before the Sohagiyah Canal, which feeds the Beni-Smia basin, and it gives red water direct to the north-eastern corner of that basin, and through regulators in the transverse bank of the basin to the southern part of East Zinnar basin and the south-eastern corner of West Zinnar basin.

With our present information regarding the levels of the Nile, it is impossible to predict early in the flood whether the flood will be high or low, and in case it may prove to be the latter, it is important to utilise every means of filling the basins.

In a good flood, water should be passed through the basins as early as possible, and the relief of a basin on to the Nile or the Yusufi can generally be commenced when the basin is from 50 to 30 centimetres below 'full irrigation' level. This level being fixed at the northern end of a basin presupposes a certain slope in the water surface from that end to the southern end where the land is highest, and, as this slope may be increased by augmenting the discharge through the basin, it follows that when 'relief' is in full operation the highest land in the basin may be flooded though the water level at the southern end is below full irrigation level. Even if the basin has afterwards to be brought to this level, it is an advantage to begin relief beforehand, so that the level may be raised gradually through the last thirty centimetres. Otherwise the basin level may rise above 'full irrigation,' and it may be necessary to close off the basin feeders to prevent an accident. This occurred last year in the Garnusi basin, which in September was allowed to get ten centimetres

above full irrigation level, and, as the Yusufi banks began to slip, it was necessary to partially close the regulators feeding the basin for a few days, in order to reduce the water level. Had relief been commenced in time, this reduction of supply would have been unnecessary. The failure of the Damraniyah syphon in the Fifth Circle was due to the supply in the Damraniyah Canal being too quickly reduced in order to avoid flooding flood sorghum in the Samhud basin, and might have been avoided had the regulators in the Samhud transverse bank been open for relief.

All basin feeders should be kept open as late as possible, and supply should be reduced only when the escapes prove insufficient to keep the basins from rising too high.

Some basins, notably Salaqusi in Minia, and Hod El-Gharbiyah in Girga, have no masonry escapes, and water cannot be passed through them. The land in these basins is very poor, and will not improve until regulators are built.

Water is passed from the Fourth to the Third Circle through the Komi bridge in the Riqqah transverse bank, and the bridge is opened whenever the inspector of the Third Circle asks for water. As a rule the regulator is not opened till late in the flood, and it would be an advantage if both the Sabah and Komi bridges were fully open so long as the Koshesha escape is open, as red water would then be drawn through the escape on to the Riqqah basin.

At the end of the last flood the Komi bridge was closed on the demand of the chief engineer of Gizeh at too early a date, and this hindered the discharge of the Riqqah basin. Rules have been made which will prevent this happening in the future.

Zinnar basin, the most northern basin of the Girga Directorate, and Mallah basin, the most southern of the Fourth Circle, are connected by an old regulator with five openings of 3·00 metres, known as the Gebel Asyut bridge. Zinnar basin and five basins to the south of it are supplied by the Sohagiyah Canal. The area of the six basins is 110,600 acres and, assuming that the basins take 40 days to fill and that the average depth of water is 1·25 metre, the mean discharge of the canal that supplies them should be 163 cubic metres a second.

Except the Ibrahimiyah Canal, the Sohagiyah is the largest canal in Upper Egypt. Between the 15th August and the 30th September its discharge varied from 380 to 520 cubic metres a second in 1892, and from 350 to 430 metres a second in 1893, a year of comparatively low flood. In the latter year the canal carried more than twice the volume required for the basins to the south of the Gebel Asyut bridge, and there was therefore a large surplus available for the northern basins. The late Colonel J. C. Ross, in his notes on the basin systems, stated that in a low Nile at least 5 million cubic metres per diem, or nearly 60 cubic metres a second, should be passed on to the north of Asyut, and there can be no doubt it would be an advantage to pass on a larger volume when it is available. Mr. Willcocks, when inspecting the country with a view to the adjustment of the land tax, found the landowners of the northern basins unanimous in demanding an increased supply from the Sohagiyah Canal. The Ibrahimiyah Canal gives these basins red water direct, but it is the north-eastern parts of the basins that get the benefit of this. An increased supply from the Sohagiyah Canal would improve the western parts of the basins, and would increase the supply in the Bahr Yusuf and improve the conditions of the basins dependent on it.

To facilitate regulation, cills have been built in the Gebel Asyut bridge, and these will be lowered before next flood, iron grooves being at the same time fixed

in the existing stone grooves so as to reduce the friction in getting down the planks. The discharge through the bridge will in this way be increased, but this will not have much effect, as the Mallah basin is small and the discharging capacity of the bridges in its cross banks is insufficient. In 1896 the Gebel Asyut bridge was left open until Mallah basin reached full irrigation level early in September, and it then had to be partially closed. By increasing the waterway of the Gebel Asyut bridge the Mallah basin will be brought to full irrigation level more quickly, and regulation on the Gebel Asyut bridge will have to be commenced at an earlier date.

To properly utilise the Sohagiyah water, it will be necessary to restore a regulator in the old Zinnar transverse bank and to make some further changes, a project for which is being prepared.

The boundary of the Fifth Circle and Girga Directorate is the Samhud transverse bank, in which there are two bridges with openings having a total width of 12 metres. The Samhud basin is supplied direct from the Nile by the Damraniyah Canal and by three feeders from the Rashwaniyah Canal; its area is 23,000 acres, but this is much restricted by flood sorghum cultivation.

Assuming that the whole of the basin is to be covered to a depth of 1·25 metre in 40 days, the average supply required is 35 cubic metres per second. In August and September 1892, the discharge of the Damraniyah Canal varied from 26 to 70 cubic metres per second and averaged 55 cubic metres per second; in 1893 the discharge varied from 33 to 46 cubic metres and averaged 42 cubic metres per second. Even in the latter year the discharge was considerably in excess of that required by the basin, not taking into account the water supplied by the three feeders from the Rashwaniyah Canal and the reduction of the flooded area of the basin by flood sorghum crops.

Beni-Himel west basin, to the north of the Samhud bank, gets red water from the Rashwaniyah Canal by the Abu-Boghar Canal, and the land in the basin is very good. Except during a low flood, this basin has not of recent years been supplied from the Damraniyah Canal through the regulators in Samhud bank. These bridges should, however, be left open at the beginning of the flood, so as to draw the red water of the Damraniyah Canal and the Rashwaniyah feeders to the north-western corner of the Samhud basin and into Beni-Himel west basin; they should then be gradually closed so as to let the water rise in the Samhud basin, but in a good flood care should be taken to open them for relief before that basin reaches its full irrigation level; this will obviate the necessity for closing the head of the Damraniyah Canal, though it may be necessary to regulate on it and reduce its discharge.

In Minia and northern Asyut all the basins reached full irrigation level before the end of September, except the Qum and Tahawi basins, which were a few days later, and Salaqusi basin, which was purposely kept low owing to the want of an escape. The Minia basins filled earlier than usual, and there is no doubt that this was due largely to the Etsa Canal.

The Beni Suef basins reached full irrigation on the following dates:—

Basin Sultani	on the 19th October
„ Nina	„ 19th „
„ Nuerah	„ 6th „
„ Kosheshah	„ 13th „
„ Riqqah	„ 24th „

Nina basin is always late, as owing to the insufficient waterway of the syphon of the feeder canal under the Ibrahimiyah Canal, this basin has to be brought to its full level from Sultani basin.

Riqqah basin was kept low to prevent damage to the sorghum crops grown in it; it could have been brought to full level at an earlier date.

Kosheshah basin was within 10 centimetres of its full irrigation level from the 1st October, and was purposely kept at that level till the 13th October to reduce wave action on the banks.

South of Asyut many of the basins were full before the 15th September, and nearly all before the end of that month. A few basins were kept low in order to prevent the sorghum in them being flooded, and were brought to full irrigation level just before the time of discharge.

As mentioned in last year's report, the full irrigation level of many basins has to be regulated by the area under flood sorghum and varies in different years. The sorghum grown in the basins gives the engineers a great deal of trouble, especially when it is in scattered plots. On the one hand they try to avoid flooding the sorghum, which is surrounded by small banks thrown up by the cultivators; and on the other hand they must irrigate all the uncultivated land, and the higher parts of the basin are not flooded for a long enough period.

Mahmud Bey Sidki draws special attention to the difficulties experienced in regulating the level of the Galawiyah basin in the Akhmim system. He states that about half of the basin was under flood sorghum, and as it is the tail basin of the system, it was not easy to carry on the relief and at the same time maintain exactly the level required.

Flood sorghum grown year after year in the same land makes it salt, from the accumulation of the deleterious salts used in the manure applied to it. Wherever land has deteriorated, efforts should be made to induce the cultivators to abstain from planting flood sorghum for one or two seasons, so as to allow of the land being thoroughly flooded. In some cases the people have arranged to do this of their own accord.

The discharge of the systems of basins in southern Asyut and Girga was commenced from the 1st to 3rd October, except that of the Abnub system, which, on the demand of the landowners, was postponed till the 8th of that month. The discharge of the systems in the Kena province, and of the Ramadi system in the Assuan province, was commenced on the 1st October. The discharge of most of the basins was completed by the 25th October, and of the rest by the end of the month. The high level of the Nile at the end of October and in November delayed the drainage of the lower lands.

Judging from the Asyut gauge, the maximum effect of the discharge of the southern basins was felt there on the 13th October, and the level of the river there was raised 0·80 metre by the discharge.

At the commencement of the discharge the condition of the Asyût-Kosheshah system of basins was very similar to what it was in the preceding year. The basins were at or above their full levels with the exception of the Sultani and Nina basins in the Beni Suef province, and these were brought to full level before the Asyut and Minia water reached them.

The dates of the main discharge operations in 1895 and 1896 are shown below:—

	1895	1896
1. Closure of feeders from the Ibrahimiyah Canal and of Gebel Asyut bridge . .	Oct. 5	Oct. 5
2. Closing head of Sabakhah Canal and reducing supply in Bahr Yusuf. . . .	Oct. 15	Oct. 20
3. Opening Delgawi escape	Oct. 11	Oct. 15
4. Opening Kosheshah escape . . .	Oct. 19	Oct. 23

It was at first proposed to open the Delgawi escape on the 11th, and the Kosheshah escape on the 19th October, as in 1895, and the Ibrahimiyah feeders and Gebel Asyut bridge were therefore closed on the 5th of that month. On the 9th October, it was decided to postpone the opening of the Delgawi escape till the 15th and of the Kosheshah escape till the 23rd. This change was a disadvantage so far as the Fourth Circle was concerned.

The operations between the opening of the Delgawi escape on to the Yusufi and the final opening of the Kosheshah escape on to the Nile were carried out in much the same sequence as in the preceding year. They will be found detailed in the Table on pages 132 and 133.

During the night of the 22nd October and the morning of the 23rd, fifty-eight of the lower gates of Kosheshah escape were raised 2 metres, and at 11 o'clock on the morning of the 23rd the upper gates were released. At the time of opening the upper gates, the level upstream of the escape was 26·68 and downstream 25·90; there was a head of 0·78 metre on the gates. After opening, the gauge downstream of the escape rose 0·43 metre. The maximum effect of the discharge was felt at Lahun on the 24th and at Kosheshah and Cairo on the 25th.

The discharge of the basins in the Asyut Province was completed by the 31st October; of those in the Minia Province by the 10th November, and of those in the Beni-Suef Province by the 15th November. The high level of the river in November delayed the discharge of the more northern basins.

In the Asyut Province, the discharge of the basins to the east of the Ibrahimiyah Canal was carried out by making the usual cuts on the 13th and 14th October.

It is to be noted that the effect of the opening of the Kosheshah escape on the river at Cairo is very much reduced, owing to the escape discharging into a side channel instead of into the main channel of the river. This is shown very clearly in the following statement, which gives the gauges on the two days in 1895 and 1896 when the discharge of the escape was greatest.

	On 20th October, 1895	On 25th October, 1896
Level of Kosheshah basin	26·70	26·69
" river D. S. of escape	26·45	26·34
" " at Wastah	26·08	25·82
" " at Cairo	19·48	19·31
Fall between basin and river	0·25	0·35
" in river between escape and Wastah. . . .	0·37	0·52
" " " Wastah and Cairo	6·60	6·51
Mean fall per kilometre between Wastah and Cairo. .	0·0825	0·0824

It is interesting to note that on each day the fall at the escape was almost exactly two-fifths of the total fall between the escape and Wastah, the other three-fifths being the fall in the channel of the river, a length of about 3 kilometres.

When the river begins to fall, earthen dams are put in the heads of canals that feed the small independent systems of basins in Aswan and Edfu districts, so as to retain the water in the basins. The water is used for irrigating flood sorghum, the greater part of which is near the desert. It is usual to leave the discharge of these basins to the people interested. In 1896 the discharge was commenced between the 15th and 18th October.

In Kena, Girga and south Asyut the people like to begin sowing their lands during the first week of Baba, i.e. from the 10th to 16th October. The date on which the discharge of a system of basins should begin must depend on the length and area of the system and the number and size of the escapes, as well as on the level of water in the basins and river. In a year like 1896, from the 1st to the 5th October appears to be the best date for commencing the discharge of most of the systems.

The discharge of the long system of basins from Asyut to Kosheshah is settled with reference to the level that it is desired to have at Cairo after Kosheshah escape is opened. In 1896, it was asked that the Cairo gauge might be raised to 7·55 metres, and this level would have been nearly reached had the Kosheshah escape been opened on the 19th October, as originally arranged. The highest level actually obtained was 7·07 metres.

So far as the basins of the Fourth Circle are concerned, I am of opinion that in years like 1895 and 1896 it would be best to open Kosheshah escape fully on the 18th October; to do this the Delgawi escape should be opened on the 10th.

Care should be taken to reduce the discharge of an escape on to the Nile when the level of water in the basin falls nearly to the level of the land near the escape, as the draw of the escape cuts up the surface of the ground into channels. In some places, e.g. near the Sohag escape, the injury done by erosion during discharge has more than balanced the benefit derived from silt admitted by the escape in the early flood.

As in previous years, water was admitted into canals for the early irrigation of flood sorghum, culverts being closed and banks made in minor canals to prevent water entering basins, in which there were summer sorghum crops, before the 15th August or later date. I was in the Asyut, Girga and Kena provinces during the first half of August, and saw no land being prepared for flood sorghum before the date fixed for opening the basins. At the same time I heard complaints about the interference to traffic and to the transport of summer sorghum crops, owing to the canals having water in them. Summer sorghum should certainly be encouraged more than flood sorghum, and I am of opinion that, unless the landowners and cultivators ask to have a canal opened early, it should remain closed till the date fixed for opening the basins. Now that this date is the 10th, instead of the 15th August, there can be very little hardship to those who wish to sow flood sorghum early.

At the end of the flood, dams are made in the canals so as to retain the water in the reaches that have crops bordering them. The cultivators take full advantage of this in giving a late watering to the sorghum.

Where sugar cane is grown, the people are only too glad to have both early and

late water, and lift it as soon as it covers the bed of a canal. The Ramadi Canal gives free flow to the Mataanah and Armant canals of the Daira Sanieh when the Aswan gauge is above 5·10 metres, a rotation having been established between them by Mohamed Bey Sabri, inspector of the Fifth Circle. These estates benefited very much last year by the rise in the river in November. The inspector states that the inspector of Armant told him that, in comparison with the years previous to 1895, a saving of 2000*l.* was made this year in the cost of irrigating the crops.

North of Delgawi basin, the basins on the west of the Yusufi are incomplete. The Tunah and Beni-Khaled basins in the Asyut Province are being completed this year, so it is unnecessary to say more about them.

The land in the Minia Province is separated, so far as irrigation is concerned, from that in Asyut by the high desert opposite Sultan Hassan, which prevents water being passed on from the Beni Khaled basin to the land in Minia; and it is naturally divided into two systems by the high land at Bahnassa. There must therefore be two separate systems of basins in Minia :—

(*a*) between Sultan Hassan and Bahnassa;

(*b*) between Bahnassa and the northern boundary of Minia.

In (*a*) the three transverse banks, Gamadia, Shusha and Tarfa, have been made with longitudinal banks extending short distances to the south. The Tarfa transverse bank is, however, not maintained, and the cut in it remains open. The other two banks are cut during the discharge, as they have no escapes.

To the north of Bahnassa there are two banks known as Harika and Shenera, each with a short longitudinal bank to the south. Each bank is cut during discharge.

The closure of the cuts in these banks is costly. The estimated cost of closing the cut in the Gamadia bank this year is 380*l.*, and that of closing the cuts in the Shusha, Harika and Shenera banks is 321*l.*

There is no doubt that these transverse banks and short longitudinal banks have benefited the land to the south of them very considerably by holding up the water, but the benefit extends only to a short distance to the south of the banks, and the closure of the cuts every year is very costly, while the land near the cuts is damaged by excavating the earth required for the cuts; the cost of closing the cuts increases yearly.

The area of the land to the west of the Yusufi in the Minia Province is over 60,000 acres, and of this a considerable area is unirrigated when the discharge of the Asyut and Minia basins is commenced. In 1896, the unirrigated area is said to have been 10,000 acres. The object of the discharge operations is to create in the Bahr Yusuf an artificial flood to irrigate this land, which, however, receives a very insufficient flooding.

Owing to the short period during which it is flooded, and to the water that covers it having been deprived of practically all its silt and fertilising properties before it reaches it, this land is very poor. To improve it and to allow of the basins being completed, a feeder direct from the Nile, taking off to the north of Minia, is required, as well as two or three regulators on Bahr Yusuf; a project for these works will be prepared. The total cost of the work will probably not exceed 3*l.* per acre of the land benefited, and, if the works are carried out, this amount will

very shortly be recouped by increased taxes. In addition the Sultani and Nina basins to the east of Yusufi, which also suffer from the want of red water, will be greatly improved.

Before the basins can be completed and the land brought to its proper condition, a new feeder from the Nile to increase the supply of the Bahr Yusuf is absolutely necessary, but if funds are not available for the whole of the works, I am of opinion that much benefit would result if the supply of the Bahr Yusuf were increased as much as possible from the Sohagiyah Canal, as mentioned on page 126. When inspecting these lands in the flood, I found that water was passing through the desert round the Gamadia bank, so that it will be sufficient to build a regulator of moderate size in this bank. I was told that water passed round the Shusha bank also, and if so, a regulator can be made in it at a moderate cost. Both of these works are urgently required to save the annual cost of closing the cuts. A regulator on the Bahr Yusuf to feed Sultani basin would also raise the water on a considerable area to the west of the Yusufi. I hope that these works will shortly be carried out.

The following statement shows the dates on which the principal events of discharge in the Fourth Circle occurred in 1895 and 1896:—

	1895	1896
ASYUT PROVINCE.	October	October
Feeders from Ibrahimiyah Canal closed and Gebel Asyut bridge nearly closed	5	5
Cut made in Itqa longitudinal bank	10	13
" Beni-Khaled bank	11	14
Delgawi and Badraman escapes opened	15	15
Cut made in Ashmunin longitudinal bank	12	16
Umm Afrita regulator opened	12	open for tahkfif at beginning of sarf
Sabakha head closed and supply in Bahr Yusuf reduced	15	20
MINIA PROVINCE.		
Cut made at south end of Tahnashawi longitudinal bank	..	not made
Abu Ismail bridge in Tahnashawi bank	13	17
Telatah and Sabâa bridges in Tahnashawi opened	13	18
Zanubah and Nazlet El-Abid escapes from Tahnashawi opened	13	17
Cut made in Tahnashawi longitudinal bank	13	18
" El-Qurn longitudinal bank	13	18
Regulators in Qurn and Tahawi banks opened	14	19
Cut made in El-Deri longitudinal bank	14	19
Regulators in El-Deri bank opened	14	19
" Menqatin and Membal opened	15	19
Gamal escape and regulators in Garnusi bank opened	16	20

	1895	1896
MINIA PROVINCE—*continued.*	October	October
Cut in Salaqusi longitudinul bank made . . .	16	20
Cut made in Gamadia transverse bank . . .	14	19
" Shusha " " . . .	14	19
" Harika " " . . .	17	22
" Shinera " " . . .	17	22
BENI-SUEF PROVINCE.		
Upper gates of Kosheshah escape let go . . .	19	23
Regulators in Nuerah bank opened . . .	23 and 24	22
" Sultani and Nini banks opened .	23 and 24	22
Cut made in Yusifi longitudinal bank, Hod Nina .	23	27
Atwab escape opened	27	25

The following statement shows the progress made in reveting the basin banks to the end of 1896 :—

Circle and Province	Length reveted			Quantity of Stone used in 1896		Expenditure in 1896
	Previous to 1896	In 1896	To end of 1896	In New Revetments	In Repairs	
Fourth Circle.	metres	metres	metres	metres	metres	£
Beni-Suef . . .	26,242	1,953	28,195	6,452	5,090	713
Minia . . .	21,962	1,600	23,562	3,028	1,099	457
Asyut, North . .	46,492	2,258	48,750	3,821	..	735
Total . . .	94,696	5,811	100,507	13,301	6,189	1,905
Girga Directorate.						
Asyut, South . .	30,175	4,454	23,817	5,410	1,483	1,414
Girga . . .	18,363	5,905	36,080	7,171	687	1,590
Total . . .	48,538	10,359	59,897	12,581	2,170	3,004
Fifth Circle.						
Kena . . .	16,635	20,763	37,398	33,925	..	5,271
Frontier . . .	..	..	..	..	..	..
Total . . .	16,635	20,763	37,398	33,925	..	5,271

The total expenditure in 1896 was 10,180*l.*, and the length of bank reveted was 36,933 metres. In addition to the above, 2763*l.* was expended in the Fourth Circle and 738*l.* in the Girga Directorate in collecting stone."

Reviewing the Irrigation Reports for 1896, Sir William Garstin, K.C.M.G., writes:—

"A largely increasing area of 'Kêdi' or summer sorghum is annually reported. It is grown chiefly in the basins adjoining the desert where the saturation level is high. It is a costly crop to produce but at the same time a profitable one. It would be very interesting could statistics be obtained showing its annual increase. At present very little is known about it, but, as it is yearly becoming a more important factor as regards the date for opening the basins, it will be necessary to take some steps for arriving at the total area cultivated.

Cereals were good in 1896, the wheat and maize crops especially so. As a large quantity of the above is consumed in the country, it is extremely difficult to arrive at the actual out-turn.

The date fixed by Khedivial Decree for admitting the flood water into the basins was the 10th August. Owing to the large area of basin land planted out with summer sorghum, it was found necessary, in order to permit of this crop being removed, to postpone the general opening of the canals until the 15th August. Experience has shown that it is impossible to lay down an absolutely rigid date for letting water into the basins. The summer sorghum is such a valuable crop and of such importance as a food supply that it is now impossible not to take it into account. The basins containing it must therefore remain without water until it has been reaped, even though a certain amount of fertilising deposit be consequently lost. This delay makes, at most, a difference of some ten days in the date of opening.

This latter varies according to the localities. Thus in the Keneh and Esneh districts the basins can well be opened by the 10th August, while further north the date must be the 15th.

Mr. Wilson gives a long and very interesting account of the operations of basin regulations in his Report. Any one studying the above will understand the care which has to be bestowed upon the manipulation of the regulating works which maintain the water levels, and the delicacy of the operation of letting off the water from the different basins and series.

The Kosheshah escape was opened on the 23rd October with a difference of level up and downstream of the regulator amounting to 0·79 metre."

In connection with the last remarks in Mr. Wilson's report, the following note on the basin lands west of the Bahr Yusuf, by Mr. A. Webb, will be interesting:—

"The Tunah and Bien Khaled basins have recently been completed and connected with the Delgawi basin, and consequently with the Sohagiyah Canal system. Their irrigation is thus assured even in very low Niles.

The areas of basin lands on the west of the Bahr Yusuf are as follows:—

	acres
Minia district	8,456
Kolosnah "	37,096
Beni Mazar "	24,709
Feshin "	13,727
Total	83,988, or 84,000 acres.

These lands were divided into basins by cross and longitudinal banks before the construction of the Ibrahimiyah Canal, but no masonry regulators existed. After the construction of the Ibrahimiyah Canal the Bahr Yusuf supply was greatly reduced and the basin banks were abandoned. Their irrigation is now effected by creating an artificial flood in the Bahr Yusuf by the rapid and almost simultaneous discharge of the Minia basins on the top of the wave caused by the discharge of the Asyut basins. The system is most unsatisfactory, as a large area of the lands is only covered for a few days by the surf water, from which the rich Nile mud has been already deposited in the Asyut and Minia basins.

These lands extend from Balansura near the southern to Talt near the northern boundary of the Minia Province. They are cut off from any connection with the Asyut basins by the high desert lands at Balansura, and are naturally divided into systems by the high desert lands at Behnessa. A project has lately been drawn up for the proper irrigation of these lands; briefly it is as follows:—

(*a*) *Southern System.*—From Balansura to Behnessah. This will consist of the following basins:—

Tukh el Khel Gamadir Shushah Tirfa El Der	Cross and longitudinal banks will be restored, and provided with masonry regulators and escapes. Old canals will be restored, and provided with regulating heads.

A main regulator and lock will be built in the Bahr Yusuf, north of Balansura.

(*b*) *Northern System.*—From Behnessa to Talt. This will consist of the following basins:—

Bortabat El Kayat El Haribah Shenara Delhanis	Banks as in southern system.

A main regulator and lock will be built in the Bahr Yusuf, north of Behnessa.

The cost of the project is about 200,000*l.*

The area of the land in the Beni-Suef Province is about 21,000 acres, which is now irrigated atthe same time as the Kosheshah basin."

As this book is passing through the press, the Government has received from the Caisse of the Public Debt the money necessary for the execution of these works. They will be some of the most profitable works executed since 1884.

CHAPTER V.

PERENNIAL IRRIGATION IN UPPER EGYPT.

Details of areas under perennial irrigation in Upper Egypt—The Ibrahimia Canal—Summer discharges—Value of summer irrigation—Estimate of crops—Basin and perennial irrigation compared—Number of engines and pumps, details of works, cost of maintenance—Detailed information about the Ibrahimia Canal—Silt deposits and silt clearance of the Ibrahimia Canal—Table of gauges, discharges and cubic metres of silt clearance, 1881–1898—Distribution of summer supply between Upper and Lower Egypt—Table of distribution from 1881–1898—Reports on the silt clearance of the Ibrahimia Canal—Sir Colin Moncrieff, 1887—Colonel Ross, 1891—Major Brown, 1892—Mr. Wilson, 1896—Ibrahimia silt deposits and Rayah Menoufia silt deposits compared—Distribution of supply between the Ibrahimia and the Yusufi Canals—Details of discharges and duty of the Ibrahimia Canal—The Yusufi Canal and the Fayoum—Details of discharges and duty of the Yusufi Canal in the Fayoum—Period of minimum supply—Mr. Wilson's Report of 1896 on the summer irrigation of Upper Egypt—The drainage of the perennially irrigated tracts—Sir Colin Moncrieff's Report of 1884—Mr. Wilson's Reports of 1894 and 1896—Condition of Ibrahimia tracts and the Fayoum—Poor-basin lands under perennial irrigation—Proposed ameliorations for the Ibrahimia tracts—Insufficiency of canal sections in the Fayoum—Ameliorations proposed for the Fayoum—Surface of Lake Kurûn should be maintained at 1884 levels—Great future before the Fayoum if properly treated.

As the whole of Lower Egypt is perennially irrigated, and basin irrigation has been completely abandoned, the full description of perennial irrigation will be reserved for Chapter VI., which treats of the irrigation of lower Egypt. It suffices here to say that perennial irrigation direct from canals is confined in Upper Egypt to 587,000 acres (see page 23).

	acres
Assiout Province	33,000
Minia "	166,000
Beni-Suêf "	53,000
Fayûm	329,000
Geeza	6,000
	587,000

Of this area, 6000 acres lie on one of the Delta Canals and are not in connection with the Upper Egypt Canals; the area is thus reduced to 252,000 acres in Assiout, Minia and Beni-Suef on the Ibrahimia Canal proper, and 329,000 acres in the Fayûm on the Yusufi Canal, or 581,000 acres in all. The whole of the Province of the Fayûm is under perennial irrigation, while in the other three provinces there is a narrow strip of land bordering the Nile in the extreme northern part of Assiout and the

southern half of Minia; in the northern half of Minia the strip is broad and embraces the greater part of the Nile valley, while in Beni-Suef Province the strip is a narrow one south of the town of Beni-Suef, but widens out considerably in the rich lands north-west of the town.

The Ibrahimia Canal is the only perennial canal in Upper Egypt which takes its water direct from the Nile. It was completed in 1873 by Baghat Pasha. Taking out of the Nile near Assiout it runs for 268 kilometres along the high land near the river. It also supplies water to the Fayûm with a summer discharge varying from 7 to 20 cubic metres per second by the Yusufi Canal. The discharge of the Ibrahimia Canal varies from 24 to 80 cubic metres per second in summer, according to the condition of the river. The area commanded by the Ibrahimia is protected from the basins by longitudinal banks called "Moheet," and all land west of this bank is under basin irrigation. In addition to supplying summer water to the lands enjoying perennial cultivation, the Ibrahimia supplies red water in flood to the basins by eight heads discharging into the basins. These heads serve also as escapes for the excess water in the Ibrahimia in flood.

In all perennially irrigated tracts the year is divided into three seasons, as already described. The summer crops are sugar cane, cotton, millets, vegetables and gardens, while clover is irrigated up to May. The summer is followed by the Nile or flood season, when the whole country is irrigated. The flood crops are millets and rice. The third season is winter, when the crops are wheat, beans, barley and clover.

The comparative importance of the different seasons is best obtained by considering the value of the crops matured. Taking the total area under perennial irrigation in Upper Egypt as 581,000 acres on the Ibrahimia Canal, the table on page 138 gives the results.

As the total area of Upper Egypt is 2,319,000 acres, valued at a gross yield per annum of 15,585,500*l.*, and 581,000 acres of perennially irrigated land have a gross yield of 4,540,000*l.*, and 6000 acres on the Lower Egypt system with a yield of 60,000*l.*, the balance of 1,732,000 acres, which is under flood irrigation, has a gross yield of 10,985,500*l.*, or 6·3*l.* per acre.

It will be noted that only 33 per cent. of the area is under summer crops, 50 per cent. under flood crops, and 70 per cent. under winter crops. This is owing to the undeveloped condition of the Fayûm. If the Ibrahimia tracts alone are taken, it will be seen that 50 per cent. of that area is under summer crops, 40 per cent. under flood, and 60 per cent. under winter crops.

If the whole of this area had been under flood irrigation, we should have had 10 per cent. or 58,000 acres under summer crops at 8*l.*, valued at 460,000*l.*; 15 per cent. or 87,000 acres under flood crop at 4*l.*, or 350,000*l.*; 95 per cent. or 550,000 acres under winter crop at 4*l.*, or 2,200,000*l.*; total 581,000 acres at 5·2*l.* = 3,010,000*l.*

This would have meant a gross yield per annum of 1,500,000*l.* less than at present.

The mass of this irrigation is free flow or flush. The flush irrigation is supplemented by 1540 water-wheels, 22 portable engines of 284 horse-power, and 28 stationary engines of 321 horse-power.

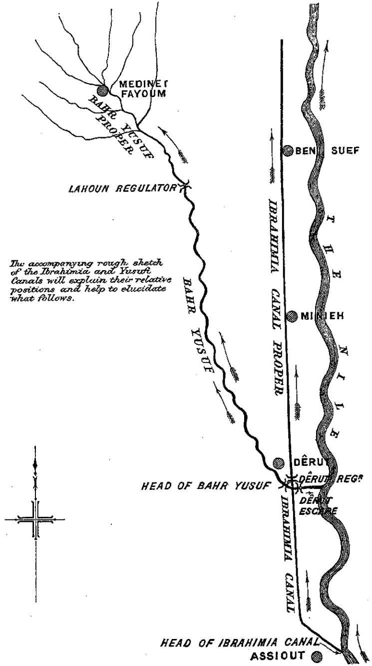
The number of masonry regulators is 182, of escapes 43, and of syphons 9. The kilometres of canals is 2197, and of drains 659.

The prime cost of all these works may be put down approximately at 3,200,000*l.*, or 5·5*l.* per acre on 581,000 acres.

The earthwork maintenence costs 40,000*l.* per annum, the masonry work maintenance 3000*l.*, and the flood protection 1000*l.* per annum. The cost of maintenance per acre on 581,000 acres is ·08*l.* per annum.

PERENNIALLY IRRIGATED TRACTS: UPPER EGYPT.

Name of Crop.	Assiout, Minia and Beni-Suef			Fayûm			Total		
	acres	per £	£	acres	per £	£	acres	per £	£
				Summer Crops.					
Sugar cane . .	55,000	16	880,000	..	..	..	55,000	16	880,000
Cotton . .	40,000	14	560,000	55,000	6	330,000	95,000	..	890,000
Gardens, vegetables, &c. .	5,000	10	50,000	15,000	10	150,000	20,000	10	200,000
Summer sorghum	25,000	6	150,000	..	..	..	25,000	6	150,000
	125,000	13	1,640,000	70,000	..	480,000	195,000	..	2,120,000
				Flood Crops.					
Flood sorghum .	100,000	4	400,000	150,000	4	600,000	250,000	4	1,000,000
Rice . . .	..	..	..	20,000	4	80,000	20,000	4	80,000
	100,000	4	400,000	170,000	4	680,000	270,000	4	1,080,000
				Winter Crops.					
Wheat . .	20,000	4	80,000	60,000	4	240,000	80,000	4	320,000
Beans. . .	30,000	3	90,000	60,000	3	180,000	90,000	3	270,000
Barley . .	10,000	3	30,000	20,000	2½	50,000	30,000	..	80,000
Clover . .	100,000	4	400,000	110,000	..	270,000	210,000	..	670,000
	160,000	3·8	600,000	250,000	..	740,000	410,000	..	1,340,000
Total area perennially irrigated.	252,000	10·5	2,640,000	329,000	6	1,900,000	581,000	8	4,540,000



MEDINET FAYOUM
BAHR YUSUF PROPER
LAHOUN REGULATOR
The accompanying rough sketch of the Ibrahimia and Yusuf Canals will explain their relative positions and help to elucidate what follows.
BAHR YUSUF
IBRAHIMIA CANAL PROPER
BENI SUEF
MINIEH
THE NILE
DÊRUT
DÊRUT REGR
DÊRUT ESCAPE
HEAD OF BAHR YUSUF
IBRAHIMIA CANAL
HEAD OF IBRAHIMIA CANAL
ASSIOUT

The Ibrahimia canal has no masonry head work. About 1 kilometre from the head it is crossed by the Upper Egypt Railway, with an opening for boats 11·80 metres wide. At the 62nd kilometre is the Dêrut regulator with a cluster of six masonry works. Beginning on the left hand the works are as follows:—

—	R.L. of Floor	Openings No.	Openings Width	R.L. of Up-stream H.W L.	R.L. Top of Wing Wall	—
	metres	mtrs.	metres	metres	metres	metres
Delgâwi Canal Head .	42·715	2	3·0	47·50	47·515	R.L. ground 45·00
Bahr Yusuf Head .	39·315	5	3·0	,,	,,	Lock 35 × 8·5 × 2
Deirûtia Canal Head .	40·115	3	3·0	,,	,,	
Ibrahimia Canal Regr.	39·315	7	3·0	,,	,,	,, ,,
Sahilia Canal Head .	40·915	2	3·0	,,	,,	
Escape Head . .	42·965	5	3·0	,,	,,	Lock 35 × 8·5 (flor. R.L. 41·315).

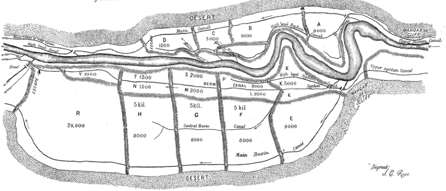
Of these locks the Bahr Yusuf head lock is fully open in flood and boats can shoot it; during summer it works. The Ibrahimia Canal regulator lock works except when silt deposit interferes. The escape head lock does not work.

The R.L. of water surface at the head of the Ibrahimia Canal is 51·75 metres in an ordinary flood, and was 52·75 in 1887; the ground level is 51·80 (R.L.); during summer the R.L. of the ordinary water surface is 45·05 metres. At Deirût the R.L. of ordinary flood is 45·23, while in 1887 it was 47·50; the ordinary summer R.L. of water surface is 43·50. During flood the downstream gauge at Deirût on the Ibrahimia Canal is kept at R.L. 44·50 metres, the canal at Minia not being able to carry more.

The remaining masonry works on the Ibrahimia Canal are the following:

R.L. of Ground	Name of Regulator	Kilo. from Head	Openings		R.L. of Floor	R.L. of Water Service				Height of Wing Wall	Lock
						Flood		Summer			
			No.	Width		Up-stream	Down-stream	Up-stream	Down-stream		
metres		mtrs.	mtrs.	mtrs.	metres	metres	metres	metres	metres	mtrs.	metres
39·50	Minia .	127	3	3·0	35·28	40·81	40·59	40·01	38·29	5·33	Lock 35 × 8½ × 2, not working
35·60	Matâi .	169	6	2·5	32·77	36·87	36·22	36·32	35·81	4·40	Ditto, partly incomplete
33·50	Magâga .	197	5	2·5	30·83	34·58	34·03	33·93	32·92	4·00	,,
	Sharahna	221	2	3·0	29·00	31·63	..	30·73	..	3·26	

GENERALISED MAP OF TWO SYSTEMS OF BASINS & CANALS UPPER EGYPT



"Signed: S. G. Rose."

The bed-width of the Ibrahimia Canal from the head to Deirût is 50 metres; below Deirût the width is 30 metres, and about 20 metres at Minia. In flood the depth of water at the head of the Ibrahimia is about 9 metres, and below Deirût 5 metres; during summer the depth of water is about 3 metres at the head, and 2 metres below Deirût. The bed is dredged on a slope of $\frac{1}{40000}$. The R.L. of the bed at the head is 42·30 metres. The discharges at Deirût are as follows:—

	cubic metres per second	
Ibrahimia above Deirût . . .	60	in summer.
” ” . . .	800	in high flood.
” ” . . .	175	in winter.
Ibrahimia below Deirût . . .	40	in summer.
” ” . . .	120	in flood.
” ” . . .	50	in winter.
Yusuf Canal	15	in summer.
”	375	maximum possible in flood.
”	300	ordinary maximum in flood.
”	35	in winter.

Though the slope of bed is only $\frac{1}{40000}$, it must be remembered that the depth of water in flood varies between 7 and 10 metres, and the slope of water surface is between $\frac{1}{10000}$ and $\frac{1}{12500}$.

The Deirût escape discharges as a maximum 400 cubic metres per second in flood.

The escapes from the Ibrahimia Canal to the Nile are—

1. Deirût escape.
2. Maâsara escape near Samalût, two openings.
3. Abâdia escape near Feshn, four openings.
4. Saida escape near Beni-Suef.

As originally designed the R.L. of the bed at the head was 43·00 metres, with a slope of $\frac{1}{16666}$ for 200 kilometres to Magâga, and then a slope of $\frac{1}{13333}$ to the tail. The depth of digging at the head was 9 metres, at Magâga 2 metres, and 1·4 metre at the tail.

As the Ibrahimia Canal takes direct from the Nile without any regulating work in the river itself, its water level depends entirely on that of the Nile. Its discharge depends on the level of the Nile and the depth to which it has been cleared. To keep the canal clear of silt, or to quickly remove silt which may have deposited in flood, is of prime importance, and for this purpose a number of powerful dredgers are kept at the head of the canal. Mean low water at Assiout is R.L. 45·05, and an effort is made to clear the canal to R.L. 42·30, leaving a mean depth of water in the canal of 2·75 metres. The following table gives the minimum Assuân and Assiout gauges of the year, the theoretical depth of water, actual measured discharges, and the cubic metres of silt clearance per annum. It will be noted

that the quantities of silt vary very considerably. This question will be fully considered a little later.

IBRAHIMIA CANAL AT HEAD.

Year	Minimum Assuân Gauge	Minimum Assiout Gauge	Theoretical Depth of Water in Canal in metres	Discharge of Canal in cubic metres per second	Cubic metres of Silt Clearance
1881	·00	?	2·75 ?	35	428,000
1882	−·55	?	2·20 ?	29	728,000
1883	+·04	−·07	2·68	50 ?	990,000
1884	+·37	+·35	3·10	71	1,147,000
1885	−·44	−·25	2·50	51	787,000
1886	−·06	+·09	2·79	61	461,000
1887	−·03	+·21	2·96	64 ?	523,000
1888	−·08	−·08	2·67	52	447,000
1889	−·60	−·55	2·20	24	629,000
1890	−·60	−·62	2·13	27	493,000
1891	−·21	−·29	2·46	29	836,000
1892	−·64	−·51	2·24	31	413,000
1893	+·35	+·13	2·88	52	372,000
1894	+·06	−·12	2·63	50	448,000
1895	+·78	+·41	3·16	75	351,000
1896	+·49	+·21	2·96	61	300,000
1897	+·62	+·54	3·29	81	214,000
1898	..	−·27	2·48	60	248,000

It may be interesting at this stage to compare the minimum supplies actually taken in summer by Upper and Lower Egypt for their perennially irrigated tracts with the supplies available, and also with the theoretical quantities which should suffice to meet all requirements. It may be taken as an axiom to day in Egypt that half the total area under cultivation will be under summer crops. A supply of 22 cubic metres per acre per day, or 4000 acres per cubic metre per second, suffice for ordinary summer crops in Lower Egypt. In Upper Egypt a reduction of one-fourth of the number of acres must be made to allow for the greater heat and evaporation. The Lower Egypt allowance is therefore 1 cubic metre per second per 4000 acres, and the Upper Egypt 1 cubic metre per second per 3000 acres. Lower Egypt, out of a total area of nearly 4,000,000 acres, has 3,438,000 acres under cultivation. Upper Egypt, out of a total of 581,000 acres, has 252,000 acres under cultivation on the Ibrahimia Canal, but of the 329,000 acres in the Fayûm only 260,000 acres may be considered as cultivated. The total area actually under cultivation in Upper Egypt is therefore 512,000 acres. In Lower Egypt and in the Ibrahimia Canal tracts summer irrigation is fully developed, and half the lands are under summer irrigation, while in the Fayûm development is still very backward and consider-

ably under one-third the area is under summer crops. If, therefore, we take half the cultivated area of Lower Egypt and allow 4000 acres per cubic metre per second, we shall find that the water needed for Lower Egypt in summer is 430 cubic metres per second. If, again, we take half of the Ibrahimia tracts, or 126,000 acres, and one-third of the developed area of the Fayûm, or 86,000 acres, or in round numbers 210,000 acres in all, and allow 3000 acres per second, we shall find that the water needed by Upper Egypt in summer is 70 cubic metres per second. Upper Egypt should therefore have about 15 per cent. of the whole supply available.

The following table has been made up on these bases. The discharge available in the Nile has been taken from the discharge corresponding to the minimum gauge at Assuân for the year, supplemented by the infiltration water which enters the Nile. This infiltration water is considerable after good and late floods like 1891, and is reduced to a minimum after bad and early floods like 1888. The total summer supply available in the Nile in 1878 and 1889 was 224 cubic metres per second, of which Upper Egypt took 24 and Lower Egypt 200, as against 34 and 190, their just shares. In 1898, with a supply of 430 cubic metres per second available for the whole country, Upper Egypt took 60 and Lower Egypt 370, which was as near as possible their fair share of the water.

SUMMER DISCHARGES: UPPER AND LOWER EGYPT.

Year	Discharge Available in Nile	Upper Egypt Discharges		Lower Egypt Discharges		Theoretical Discharge Required		
		Proportion Due	Actually Taken	Proportion Due	Actually Taken	Upper Egypt	Lower Egypt	Total
1881	450	70	35	380	140	70	430	500
1882	280	45	29	235	120	„	„	„
1883	450	70	50	380	135	„	„	„
1884	600	90	71	510	300	„	„	„
1885	350	50	51	300	300	„	„	„
1886	440	45	61	395	300	„	„	„
1887	440	45	64	395	300	„	„	„
1888	440	45	52	395	300	„	„	„
1889	224	34	24	190	200	„	„	„
1890	277	45	27	222	250	„	„	„
1891	400	60	29	340	370	70	430	500
1892	331	50	31	281	300	„	„	„
1893	600	90	52	510	400	„	„	„
1894	480	70	50	410	370	„	„	„
1895	760	115	75	645	400	„	„	„
1896	670	100	61	570	380	„	„	„
1897	720	110	81	610	400	„	„	„
1898	430	65	60	365	370	„	„	„

The cost of silt clearance of the Ibrahimia Canal has, as already stated, been no inconsiderable item in the budget of the Fourth Circle of irrigation, and its reduction has engaged the most serious attention of the irrigation officers. Sir Colin Scott-Moncrieff, in the Report of 1887, wrote as follows :—

"As stated in former Reports, the chief source of expense on the Ibrahimieh Canal is dredging. The following figures show the progress made in reducing it.

—	Cubic metres Dredged			Expense
	Assiout to Deirut	Below Deirut	Total	
				£
1884	818,430	330,268	1,147,690	34,656
1885	604,598	182,314	786,912	35,662
1886	461,363	..	461,363	24,429
1887	523,410	..	523,410	26,124

In former Reports it has been shown how dredging is no longer required in the Ibrahimieh Canal north of Deirut, and in the Report for 1886 it was stated that to diminish the dredging south of this point, Captain Brown had been narrowing the bed of the canal by placing in it a series of stone groynes or spurs. He erected 12 pairs of these groynes in 1886 at a cost of 2108*l.* In 1887 he erected 14 pairs and repaired former ones at a cost of 2403*l.* The result has been very satisfactory. The heavy dredging formerly necessary north of Manfalut will probably not be required again, and when the spurs are erected along all the portions requiring dredging, we may hope to reduce it to a very small volume."

Colonel J. C. Ross, in the Report for 1891 has the following :—

" Major Brown writes on the subject of dredging the Ibrahimia Canal :

'When the preliminary sounds of the bed of the Ibrahimiyah Canal between Asyut and Derut were taken in December 1890, it was ascertained that there were unusually large deposits of silt between the mouth of the Ibrahimiyah and the 10th kilometre where the continuous line of spurs commences, and below kilometre 34 where the spurs end. The large quantity of deposit in the first 7 kilometres was most formidable, and early in the year affected the discharge most seriously. There was nothing to be done but to order the contractors to dredge away as hard as they could. The two dredgers that worked between kilometre 5 and 13, where the heaviest dredging was done, worked downstream. The current over the high parts of the beds was very strong, and must have carried much of the silt that was disturbed by the buckets, but not lifted, forward downstream of the dredger. As the dredgers worked, the heaps moved downstream, and though the quantities returned as dredged were very high, the quantity still remaining in the bed did not proportionately decrease. It is easy to understand how favourable to the contractor working downstream is at points

where the current is strong and work is estimated by forward and after sections taken after the dredger has been at work. The bed from 8 to 10½ kilometres, which had been dredged clean by the forward dredger, was filled up by a fresh depth of nearly 2 metres of silt as the after dredger advanced, so that this length of 2500 metres had to be dredged twice.

'By the end of the season, the first 7 kilometres of the canal were quite clear, but there were lengths of 1 kilometre at kilometres 8 and 11 where the bed was half a metre to a metre higher than the true bed, and again a kilometre length about half a metre above true bed at kilometre 14. These points were being dredged when the news from Aswân enabled me to stop dredging.

'Five dredgers were kept at work for the greater part of the season, and some of them had to constantly work extra hours. The state of the bed in the early months of the year gave great cause for anxiety, lest the discharge should have fallen too low to meet the requirements of summer irrigation. Fortunately the efforts to clear the bed were sufficiently successful, and scarcity of water was not felt anywhere. The cotton and millet crops were fine ones, and I believe the sugar cane crop will be the largest on record. This must be our consolation for the heavy expenditure incurred on the dredging. The heaviest silting was between kilometres 3 and 10. The line of spurs was continued over this length in 1891, and it was found in January 1892 that this length was generally half a metre lower than the required bed. The dredging in the first 5 kilometres in 1892 will be as usual, but below kilometre 5½ the bed is almost clear to kilometre 12, where a heap, a kilometre long and 3 metres high, exists, moving forward at the rate of 30 metres a day and decreasing as it moves. There is another similar high heap about kilometre 17. The bed is then practically clear to kilometre 34, where the spurs end. From this point the bed is high for 4 kilometres, which I propose to spur in 1892. There are heaps again from kilometres 45 to 48½, from kilometres 51 to 53½, and from kilometres 57½ to 58½. The last will certainly disappear by scour, the last but one will probably disappear if not entirely nearly so, and the third will probably scour away sufficiently to make it unnecessary to dredge it.

'The quantity dredged during 1891 was 836,116 cubic metres, at a cost of 30,591*l.*, made up as given below:—

'To Messrs. Duport and Jones.		
For dredging	£30,325	
Sand removal	177	
		30,502
Sounding, establishment, &c.		89
Total		£30,591

'In consequence of this high expenditure and the unsatisfactory result of the measurements, I have asked that a special engineer with proper technical knowledge and powers of observations be put in charge of the measurements at least for one year, but my application has been refused.

The figures for past years are as follows:—

L

Year	Asyut to Derut	Below Derut	Total	Cost
				£
1884	818,430	330,268	1,147,690	34,656
1885	605,598	182,314	786,912	35,662
1886	461,363	..	461,363	24,429
1887	523,410	..	523,410	23,639
1888	447,088	..	447,088	16,595
1889	629,022	..	629,022	23,071
1890	493,210	..	493,210	18,135
1891	836,116	..	836,116	30,591

'In consequence of the unsatisfactory result of dredging downstream, as remarked last year, the contractors have been ordered in 1892 to dredge upstream with all their dredgers, and have altered the shoots of two of the dredgers accordingly.'

The spurs have been advanced by 32 new pairs, but the question as to what results they actually produce is not yet settled. It is hoped that in a few years the wished-for result will be obtained.

I made a suggestion here founded on the lately understood fact that silt is formed in canals by a too high velocity as well as by a too low one. The high velocity throws down silt by the endeavour of nature to raise the bed at the expense of the slopes, and this more especially in the Ibrahimiyah, where the slopes consist at low water of a wide banquette on a low level, submerged in low flood, and the ordinary canal slope. The natural action is to drag the side silt into the middle, and thus fill in the low level channel or cuvette in which the summer water flows.

I propose therefore that in December, January and February, when there is excess water in the river, that Derut regulators should be held up as much as is possible with due regard to their safety, and that thus the velocity of the canal may be much diminished. Hitherto the contrary has been the case. Derut escape has been opened and every endeavour has been in the direction of scour. Very likely the side erosion will cease and the cuvette will not fill in.

In my opinion, and I am quite satisfied from observation, that in these large canals of Egypt, and to a less extent in smaller ones, when their sides are weak, scour produces silt on the bed and thereby ruins the summer discharge, and this is a great difference between our Indian and Egyptian experience.

Major Brown writes of the spurs as follows:—

'There is now a continuous line of spurs from 2½ kilometres to 34 kilometres. They have not, however, prevented all silting in this length, as in January 1892, as stated above, there are two heaps about a kilometre each in length, about kilometres 12 and 27, from 3 to 2½ metres above proper bed-level, which will have to be dredged. A longitudinal section taken out the 2nd January 1892, before commencing dredging, is sent with this Report. I think it probable that these two heaps in the line of spurs are due to the large amount of material dredged last year from the 5th to the 10th kilometre, which has been brought back from the berms where it was deposited into the channel. If this is the true cause, there are greater hopes that these high parts will not be found to have re-formed after next floods, or at any

rate that they be formed lower down the canal and in less quantity in consequence of this year's dredged material returning to the channel. There were 32 pairs of new spurs made in 1891. The following is the account under the head of Ibrahimiyah Defence works :—

	cubic metres	£
32 pair of spurs	14,284	2,507
Repairs to old spurs	1,982	295
Railway revetments	2,226	254
Protecting special points	1,796	230
Total		£3,286"

In the Report for 1892, Major Brown writes as follows :—

"The spurs built in 1891 kept the bed clear over the length spurred, where dredging had been necessary the year before. There was less deposit found in the bed after the flood, and dredging downstream was forbidden. For these two reasons the dredging bill was the lightest there has been since dredging has been done by contract. The prospects of 1893 are that the cube to be dredged will nearly, but not quite, come up to the figure of 1892. For the first time, the contractors have not been given the usual notice, according to the terms of their contract, that the cube to be dredged will exceed 400,000 cubic metres.

On page 78 of last year's Irrigation Report, Colonel Ross proposes that, with the view of decreasing deposit in the Ibrahimîyah, the water level at Derût regulators should be held up as much as possible to decrease the velocity of flow in the canal, and so counteract the tendency of high velocities to scour the sides, and bring material from them into the channel. That this action goes on is undoubted, but not at the time when Colonel Ross supposes. It takes place at the height of the flood, when the regulators at Derût are open, but still with the water level there at the highest safe limit. There is no possibility of checking the flow by heading up then, nor would a head regulator to the canal bring a remedy, as the discharge required for the basins is so large that the high velocity becomes a necessity during September. All that can be done is to make spurs and prevent the sides from eroding.

I believe that, if the spurs had not been made, our dredging bill would have gone on increasing from year to year from the cause pointed out by Colonel Ross, and that in bad years the quantity of dredging to be done would have been beyond the power of the dredging plant available, and have required an expenditure far in excess of our allotments. Instead of which, there are indications of a permanent decrease. I scarcely like to call them more than indications at present, as the figure for 1891 was not encouraging, but there were special reasons for the high figure of that year, and it is partly accounted for by the method of dredging downstream, under conditions most unfavourable for the employment of such a method.

But to return to an examination of Colonel Ross's proposal. It is shown clearly by soundings taken in December, January and February, that the silt previously deposited in the bed *diminishes*, doubtless by the scour of the current as the depth of water becomes less. Obviously, therefore, the proper thing to do is, not to head up at Derût, but to keep the level as low as possible with the object of increasing

the scour on the bed. This is what is always done with good effect, as is quite plain from a study of the longitudinal sections made from soundings taken every fortnight.

Colonel Ross made his proposal on the assumption, I suppose, that the deposit increases in December, January and February, which is the reverse of what takes place. The scour produced by leaving the escape open at Derût and lowering the water surface as far as possible, has been taken advantage of for some years past to decrease the deposit existing in the bed, and the commencement of dredging is postponed to as late a date as possible to give the scour time to take effect."

In the Report of 1896, Mr. Wilson writes as follows :—

"The following table shows the quantities dredged from the Ibrahimia Canal, and the costs of dredging since 1883 :—

Year	Quantity in cubic metres			Cost in £
	Asyut to Deirut	Below Deirut	Total	
1884	818,430	330,268	1,147,690	34,656
1885	605,598	182,314	786,912	35,662
1886	461,363	..	461,363	24,429
1887	423,410	..	523,410	26,124
1888	447,088	..	447,088	16,595
1889	629,022	..	629,022	23,071
1890	493,210	..	493,210	18,135
1891	836,116	..	836,116	30,591
1892	413,088	..	413,088	15,597
1893	371,926	..	371,926	14,400
1894	448,026	..	448,026	16,888
1895	351,253	..	351,253	13,225
1896	300,706	..	300,706	11,347

The quantity dredged was slightly less than that of 1895 and the lowest on record. The level of the bed at the mouth was fixed at R I 42·30, and the bed was dredged to a slope of $\frac{1}{10000}$ as in previous years. The reduction in the quantity is due greatly to the spurs, which have produced a narrower and more uniform channel than previously existed. But a great part of the decrease is due to the favourable conditions of the river at the offtake of the canal. There was a large sandbank to the south of the offtake, and the water arrived at the canal after having deposited a great part of its silt in forming this sandbank.

During the year 26 pairs of new spurs were built; a continuous line of spurs, generally at distances apart of 250 metres, now exists to kilometre 55, i.e. to within six kilometres of the Deirût escape. The quantity of stone used was 18,660 cubic metres, costing 1865*l.*; in addition 1044 cubic metres of stone, costing 125*l.*, were used in revetment of the railway bank. The progress made in the construction of these spurs, and their cost, is shown below :—

Year	Nos. of Pairs of Spurs made	Expenditure in £			
		On New Spurs	On Repairs	On Revetment of Railway Banks	Totals
1886	12	2,172	..	..	2,172
1887	14	2,390	96	..	2,386
1888	23	3,747	560	1,025	5,332
1889	31	4,366	148	558	5,072
1890	26	4,696	80	710	5,486
1891	32	2,507	295	484	3,286
1892	26	5,191	303	274	5,768
1893	3	1,396	724	35	2,155
1894	9	1,824	817	646	3,317
1895	14	1,938	361	359	2,658
1896	26	1,865	..	125	1,990
Total .	216	31,992	3,444	4,216	39,662"

When the Nile in flood comes to be considered, Mr. Ead's observations on the Mississippi will be given, but it may suffice here to state that the eminent American engineer's observations fully bear out Mr. Wilson's statement that there are two factors in the silting up of the Ibrahimia Canal, and that the amounts of the silt deposits depend as much on the condition of the river at the head of the canal as on the spurs. It will be further remembered that in Chapter III. occurred the following statement:—

"The fellaheen classify the basin canals as 'muddy' or 'sandy,' according as the water they carry is rich in slime or sand. They naturally prefer the muddy canals, of which the Sohagia is the arch type. Such canals, they say, take off severe curves of the Nile, and have no shoals or shifting islands near their heads. The sandy canals are of the type of the Girgawia (the worst of all) and the Ibrahimia, which take off straight reaches with shifting shoals near their heads. Village headmen have frequently informed me that they would far sooner have their lands in the fourth or fifth basin of the Sohagia, than in the first of the Ibrahimia or the Girgawia, which enjoy a very bad reputation. They propose the removal of their heads, but that is practically out of the question. The training of the Nile for 7 or 8 kilometres upstream of the heads of canals which are encumbered with shoals, might suffice to improve the canals."

From 1884 to 1891 the river was scouring out severely upstream of the Ibrahimia Canal, and the centre of scour was travelling northwards. In 1891 the scour was severest just upstream of the canal head. In 1892 it had just passed the head. In 1896, and more fully in 1897 and 1898, the scour has absolutely ceased near the canal head, and there are sand shoals just upstream of the head. The water in the canal is not charged with

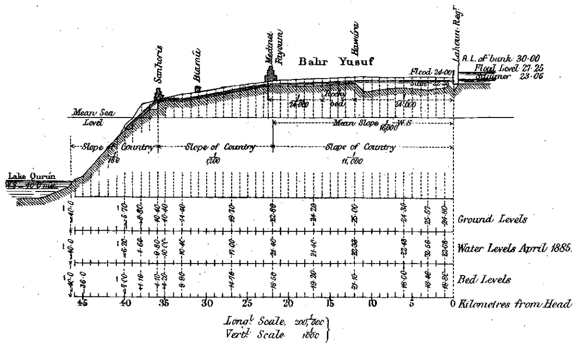
excess silt, and the spurs complete what the river has done. When we come to the Rayah Menoufia Canal in the Delta, it will be found that up to 1887 there was no silt deposited in this canal, as the scour was away from the canal head on the opposite bank of the river. Since 1887, however, an attempt has been made to scour away great part of the sandy island just upstream of the Barrages and directly upstream of the Rayah Menoufia, and the canal has silted up very considerably, and in spite of heavy expenditure on dredging has never given the discharge it gave previous to 1887, when there was no dredging whatever. The Rayah Menoufia has a slope of $\frac{1}{12500}$, a depth of 6 metres, and a velocity in flood of about 1 metre per second.

Of the discharge which enters the Ibrahimia Canal in winter and summer part is utilised, as already stated, for the perennially irrigated lands in Assiout, Minia and Beni-Suef, and part in the Fayûm. A part is also utilised for the lands bordering the Bahr Yusuf before it enters the Fayûm. This last discharge is balanced by the supplies entering the Bahr Yusuf as springs from the sandy tracts between the Bahr and the desert. These springs, however, dwindle to a very insignificant quantity after years of bad flood supply, like 1888, and when most needed are least available. This must always be borne in mind.

Since half the area on the Ibrahimia Canal, or 126,000 acres, and one-third the developed area of the Fayûm, or 86,000 acres (as already explained), are entitled to summer irrigation, a fair proportion of the minimum supply available would be three-fifths to the Ibrahimia Canal and two-fifths to the Fayûm. Moreover, allowing 3000 acres per cubic metre per second, the Ibrahimia Canal requires for its healthy irrigation a supply of 42 cubic metres per second, and the Fayûm requires 28 cubic metres per second. The whole of Upper Egypt requires 70 cubic metres per second. The actual distribution of water between the Bahr Yusuf and the Fayûm on one side, and the Ibrahimia proper on the other, is thus made in actual practice. The Bahr Yusuf receives one-fourth of the supply available + 1·2 cubic metre per second for the 4000 acres on its banks before it reaches the Fayûm, while the Ibrahimia Canal receives three-fourths − 1·2 cubic metre per second. In a year like 1896, when the minimum discharge was 61 cubic metres per second, the Bahr Yusuf received 17 cubic metres per second and the Ibrahimia 44. Allowing 3000 acres per cubic metre per second, the water given to the Fayûm sufficed for 50,000 acres, while there were actually 70,000 acres, and the water given to the Ibrahimia sufficed for 132,000 acres, while there were actually 125,000 acres. The fairer distribution would have been 25 cubic metres to the Fayûm and 36 cubic metres to the Ibrahimia.

The Ibrahimia Canal tracts have hitherto had more than their share of water and the Fayûm less. This has come about because the former has

LONGITUDINAL SECTION OF THE FAYOUM.

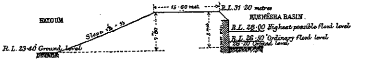


been long developed and the latter has only begun quite recently to develop its general area. The Ibrahimia tracts, moreover, are largely under sugar cane, to which in the past all other crops were subordinated, while the Fayûm is a cotton province. The Daira Sania and State Domains administrators, also, which between them own 114,000 acres in the Fayûm, or one-third the whole area, have both neglected the Fayûm, the former in the interests of its more valuable possessions on the Ibrahimia, and the latter for its valuable lands in Lower Egypt. The Fayûm, however, if skilfully handled, and no province needs more skilful handling, has a great future before it.

The Ibrahimia Canal downstream of the Deirût regulator has the following discharges. In summer the average discharge is 40 cubic metres per second, in flood 120 cubic metres per second, and in winter 50 cubic metres per second. The areas under irrigation in the three seasons are 125,000, 252,000 and 210,000 respectively. The duty in summer is therefore 3100 acres per cubic metre per second. In flood and winter only two-thirds the discharge is utilised, and the duty becomes 3000 and 5000 acres per cubic metre per second.

The Bahr Yusuf, which receives its supply from the Ibrahimia Canal at Deirût, traverses the Assiout, Minieh and Beni-Suef provinces for 316 kilometres, and finally leaves the valley of the Nile at Lahoun. After a further course of 22 kilometres it flows through the town of Medinet el Fayûm, the ancient Arsinoë. Near this town it is divided into some fourteen canals, which irrigate the Province of the Fayûm, the only oasis in Egypt in direct communication with the Nile. Three small canals, however, one on the right and two on the left, had taken off about midway between Lahoun and Medinet. The Fayûm is a veritable oasis, surrounded on all sides by desert and connected with the valley of the Nile by the thin strip of cultivation along the Bahr Yusuf.

The depression in the Libyan hills at Lahoun is about 6 kilometres wide, and across this depression there runs a very ancient bank of great height and width, which was reveted with masonry on its eastern slope in 1835. This bank separates the Fayûm from the Koshêsha basin of the



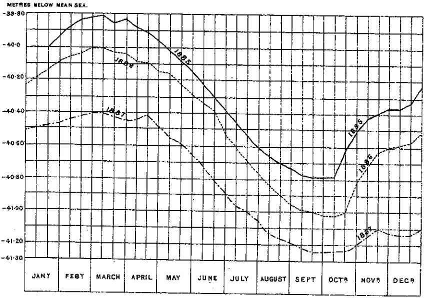
Beni-Suef Province. The preceding sketch gives the mean section of the bank, and shows the reduced level of the country and of the water in the Koshêsha basin during flood. Near the village of Lahoun the bank is pierced by a new regulator with two openings of 3 metres each, and one

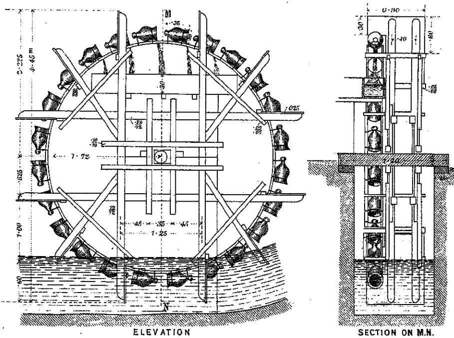
opening of 4 metres. Below it is Mohamed Aly's old regulator, which has gradually been undermined. The mean slope of the Bahr Yusuf from Lahoun to Medinet is $\frac{1}{18000}$. For the first 12 kilometres the Bahr flows within an earthen channel on a slope of $\frac{1}{24000}$, in the next 3 kilometres it is broken up into a series of rapids with a limestone bed. For the rest of its course, up to Medinet, it again flows within earthen banks on a slope of $\frac{1}{24000}$. Up to the 12th kilometre the Bahr has followed its natural channel; after this point, and if left to itself, it would have followed one of the three deep ravines on the right, and thus escaped to the Birket el Qurûm, or lake, to the north of the Fayûm. To keep up the level of water for irrigation, however, two of these three deep ravines were banked across by massive earthen embankments, while at the third an old escape head was built up. By turning the Bahr Yusuf over the limestone bars it has been kept on the watershed and rendered capable of feeding all the canals of the province. The maintenance of all these embankments in first-class order is a matter of the greatest importance. A breach would be attended with the most disastrous consequences. Breaches *are* possible, as Linant Pasha describes the carrying away of one of these embankments in 1820.

Plate XVI. gives the longitudinal section of the country from Lahoun to the lake. Up to Medinet, a distance of 22 kilometres, the slope is $\frac{1}{11000}$, the same as the general slope of Upper Egypt. From kilometre 22 to kilometre 36 the slope is $\frac{1}{1200}$. We have now reached the level of the Mediterranean. For the remaining 8 kilometres the slope is $\frac{1}{180}$. The water surface of the lake itself is about 40 metres below the Mediterranean. This longitudinal section, which is a type one of the province, shows clearly that the flat lands of the province near Medinet el Fayûm were formed by basin irrigation or by deposits above water level, while the steep slopes were deposited under water. This was in the old days when the ancient lake Moeris covered everything except the flat lands round Medinet el Fayûm. The same features are met with in the Delta when we compare the slope of the land above sea level with that below sea level along the edge of the Mediterranean. (See a description of this land in Chapter VIII. and a somewhat similar section.) From discharge observations near the head of the Bahr Yusuf a gauge of 22·33 metres R.L. in summer gives a sectional area of 147·8 metres, a slope of $\frac{1}{48000}$, a mean velocity of ·12 metre per second, and a discharge of 17·5 cubic metres per second. During flood a gauge of 23·33 metres R.L. gives a sectional area of 183,355 square metres, a slope of $\frac{1}{24000}$, a velocity of ·48 metre per second, and a discharge of 89 cubic metres per second. The bed-width is about 25 metres roughly.

On referring to the plan it will be seen that the country is cut up by deep ravines, some of which are 100 metres in width and 15 metres in

LAKE QURÚN GAUGE DIAGRAM.





UNDERSHOT WHEEL IN FAYOUM FOR RAISING WATER

Scale $\frac{1}{50}$. *Dimensions in Metres.*

depth; the two main ones are known as the Batts and Wadi el Nezla, and both tail into the Birket el Qurûm. Indeed, many of the canals are more or less ravines. It is quite a common feature in the Fayûm to see wheels lifting water by water power; while all the canals are studded with corn mills worked by turbines (panchakkis) of a pattern introduced from India some thirty years ago.

We have already considered the discharges and the duty of the Ibrahimia Canal at its head near Assiout, and of the Ibrahimia Canal proper downstream of Deirût. We have also considered the Bahr Yusuf at Deirut where it leaves the Ibrahimia Canal. It remains to consider the Bahr Yusuf proper in the Fayûm after it traverses the Lahoun Regulator. Downstream of Lahoun, where the Yusufi Canal enters the Fayûm, the discharges are as follows. In summer the average discharge is 15 cubic metres per second, in flood 82 cubic metres per second, and in winter 44 cubic metres per second. The areas under irrigation in the three seasons are, 70,000, 329,000 and 270,000 respectively. The duty in summer is therefore 4600 acres per cubic metre per second, in flood 4000 acres per cubic metre per second, and in winter 6100 acres per cubic metre per second.

In the perennially irrigated tracts of Upper Egypt, in very bad years like 1889 and 1890, the period of minimum supply lasts for forty-five days, but in ordinary years it may be considered as lasting for thirty days, Colonel Ross's report for 1891 shows the state of the Ibrahimia Canal during the two years 1890 and 1891.

IBRAHIMIA CANAL DISCHARGES.

1890			1891		
Date	Gauge	Discharge	Date	Gauge	Discharge
March 15	·41	58	March 15	·68	55
April 1	·28	46	April 1	·29	39
„ 16	−·01	41	„ 16	·09	35
May 3	−·25	35	May 1	−·09	30
„ 17	−·45	32	„ 17	−·25	29
June 1	−·58	27	June 1	−·19	32
„ 16	·58	27	„ 16	·15	43
July 1	−·05	44	July 1	1·35	100

Since 1892 there has been such an abundance of water in the Nile during the summer that there has been no difficulty in irrigation. As a specimen of all these years I give Mr. Wilson's Report on the summer irrigation of Upper Egypt in 1896.

"The volumes entering and utilised in the Ibrahimiyah Canal during the summer months of the last four years are given below in cubic metres per second :—

Month	1893		1894		1895		1896	
	Discharge at Head	Discharge Utilised	Discharge at Head	Discharge Utilised	Discharge at Head	Discharge Utilised	Discharge at Head	Discharge Utilised
April . .	134·7	79·4	65·1	65·1	121·2	84·2	100·2	86·2
May . .	82·9	67·3	58·3	58·3	92·1	87·7	75·7	75·7
June . .	56·3	56·3	69·2	69:2	81·7	81·7	64·6	64·6

It will be seen that the volume of water utilised varies according to the quantity available. In 1894 the Derut escape was closed in March, and during the three following months all the water entering the canal was used. The escape was closed in 1895 on the 10th May, and in 1896 on the 15th April.

Though the area under summer crops was larger than in previous years, little difficulty was experienced in irrigating it, except during the latter half of July, when water was required for sowing the sorghum and maize as well as for the sugar cane and cotton crops.

As in 1895, the discharge of the Bahr Yusuf was fixed at one quarter of the discharge of the Ibrahimiyah Canal at Derut plus 1·2 cubic metre per second. Owing to the severe outbreak of cholera in the Fayum at the end of June, an increased supply was sent down the Bahr Yusuf during that and the following months, so as to improve the drinking supply and obviate the necessity of imposing rotations on the canals.

On the Ibrahimiyah Canal, rotations in the Asyut, Minia, and Beni-Suef provinces were commenced on the 15th May. They were continued in Asyut and Minia till the middle of July and in Beni-Suef till nearly the end of that month. In the Fayum, owing to the cholera, no rotations were enforced

In the Report for 1895, the question of introducing a system of rotations throughout winter and summer was referred to. It is to be noted that the conditions of Middle Egypt, as regards summer rotations, differ materially from those of Lower Egypt. In the latter, the supply in April, May and June is practically assured, except in a very low year, by the two barrages, which give the power of raising the water level and sending the volume required down each of the three main canals that supply the Delta. There being no barrage in the river below the head of the Ibrahimiyah Canal, the supply in that canal cannot be regulated in this way, and is dependent entirely on the volume of water in the river.

It is customary to commence rotations in the Asyut, Minia and Beni-Suef provinces when the river gauge at Asyut falls to ·45, and in a year of average summer supply rotations are in force during April, May, June and the first half of July. In the winter, the canals are closed for from 20 to 30 days for clearance, so that in an ordinary year there are only about two months in which additional rotations can be imposed. The case is very different in Lower Egypt, where the regular summer rotations have rarely been enforced before the 20th June.

Mr. A. L. Webb, Inspector of the Fourth Circle, has carefully studied the

subject, and considers that it is not necessary to impose any further system of rotations in the Asyut and Minia provinces, but that in the Beni-Suef Province a system of winter rotations is advisable. He points out that the level of the Ibrahimiyah Canal above the Sharahnah regulator in the latter province is maintained at a high level throughout the winter, in order to give water to the canal that feeds the sugar factory at Biba, and that, if the Daira Sanieh Administration arranged to put up an engine and pump to supply the factory canal when the water in the Ibrahimiyah Canal is low, the level of the water in the latter canal might be raised and lowered in alternate periods of 8 or 10 days, and a system of rotations on the small branches taking out of the main canal would thus be automatically applied. If this were done there can be no doubt that benefit would result to the land adjoining the main and branch canals, and it is to be hoped that the pump and engine will be erected before the next working season.

In the Fayum the conditions are more similar to those of Lower Egypt, as rotations are ordinarily enforced in June and July only. A system of winter and spring rotations, by which about one and a half times the average supply could be sent down each branch canal during one period, and half the average supply during the following period, would be a great improvement, but before such a system can be applied, many of the canals must be deepened and widened so as to carry the increased supply without raising the level of the water. Mr. Webb mentions that from the 15th December to the end of February the Bahr Yusuf has to be kept unnecessarily high, so far as the rest of the province is concerned, in order to keep up the supply in the Bahr Sailah, and to remedy this it is proposed to build a regulator in the Bahr Yusuf. I hope that this regulator will be built before next winter, and that a system of winter rotations will then be commenced.

The area under cotton in Middle Egypt was larger than in any previous year. Early in the season the out-turn promised to be very good, but climatic conditions in the latter part of the season were unfavourable, and the yield was less than had been anticipated.

The following table, furnished by Mr. Wakeham, Agent of Messrs. Carver Brothers, gives the out-turn of the ginning factories in Upper Egypt:—

Province	Out-turn in Kantars or cwt.			
	Season 1893–4	Season 1894–5	Season 1895–6	Season 1896–7
Beni-Suef	85,000	120,000	150,000	154,000
Minia	30,000	50,000	82,000	107,000
Fayoum	75,000	90,00	130,000	138,000
Total . . .	190,000	260,000	362,000	399,000
Average price per cwt. .	£2·1	£1·65	£2·05	£2·05

During the last four years the out-turn has more than doubled. The increase in Minia is especially remarkable, and is due to some extent to the Daira Sanieh Administration having rented some of their lands for growing cotton.

Statements giving the quantity of cane brought to the chief sugar factories in Upper Egypt accompany the report. The crop is said to have been an excellent one.

The 'Société des Sucreries de la Haute-Egypte' has doubled the capacity of its factory at Sheikh-Fadl, and it is now capable of turning out 15,000 tons of sugar. The same company has constructed a very large factory at Naga Hamadi, which, when complete, will be able to turn out 30,000 tons. The two factories will require an area of 20,000 acres of sugar cane.

The Egyptian Sugar and Land Company is erecting a factory at Baliana to produce 9000 tons of sugar.

The area under sorghum in the basins in summer is increasing yearly. It is grown chiefly near the desert, where the ground is low and the saturation level high. It is a most valuable crop, as it is generally manured and gives a large yield. To prevent its being flooded, it was necessary to postpone the opening of some of the basins some five or six days beyond the date fixed.

The out-turn of the winter crops was said to be good, and there is no doubt that the land in the basins has been materially improved by the good floods of recent years.

A good deal of damage was done by caterpillars to the wheat and barley sown after the flood of 1895, and a considerable area had to be re-sown. I heard no complaints of this after the last flood.

The inspector of the Fourth Circle gives the following data regarding the duty of water in his circle:—

Taking the chief engineers' figures of all the summer crops irrigated by the Ibrahimiyah Canal, we have as follows:—

	acres
Asyut Province	12,220
Minia „	71,800
Beni-Suef Province	26,657
Fayum „	73,457
Total	184,134

On May 15th, when rotations commenced, the discharge of the Ibrahimiyah Canal at Asyut was 67 cubic metres per second, giving on the above area a duty of 2750 acres per cubic metre per second.

The lowest recorded discharges of the Ibrahimiyah Canal were as follows:—

At Asyut	61 cubic metres per second.
Below Derut	24 cubic metres per second.
Below Magaga	7 cubic metres per second."

The drainage question in the perennially irrigated tracts remains to be considered.

In the Irrigation Report for 1884, Sir Colin Scott-Moncrieff wrote as follows:—

"Concerning the absence of drainage, Captain Brown writes as follows: 'I do not think the importance of this drainage question can be over-rated. The state of the lands about Salakos should be taken as a plain warning as to what may be expected to appear between the *Mohit* (the embankment bounding the irrigation on the west) and the Ibrahimieh, if the present absence of all means of drainage continues.'

At Salakos there are 6000 acres of land thrown out of use. The slope of the country is naturally to the west, and these lands might be drained easily into the Bahr Yussuf, but this is the only water supply of the Fayoum, into which then the salt-impregnated water would be carried, a thing to prevent at all costs. I am glad to say there seems no difficulty in draining the swamped lands by syphons under the canal back into the Nile, and Captain Brown has submitted proposals with this object, which want of funds alone prevent our carrying out."

Many attempts have been made to reclaim these lands, but they have not met with any success.

The subject will be returned to in Chapters VII. and VIII.

The general drainage of the lands irrigated by the Ibrahimia Canal and the Fayûm has been improved during the last five or six years, but the improvements have in no wise kept pace with the increased irrigation.

In 1892, after the series of very low summer supplies in the Nile, an era of distinct improvement seemed to have set in, but the heavy irrigation since 1893 has again thrown back the question, and the greater part of the perennially irrigated tracts are more in need of drainage than ever.

In the Irrigation Report of 1894, Mr. Wilson writes as follows:—

"In Middle Egypt considerable progress was made with the main drainage lines along the bank bordering the basins. As much as 546,341 cubic metres were excavated in digging the main drain from the south to the north limit of Minia Province. This practically completes the main western and central Muhit drainage line in Minia and Beni-Suef. A short length in Asyût Province remains to be dug, but this necessitates a syphon under the Sabakhah Canal, for which no money can be spared, though it is a very necessary work.

The new Deri Canal drainage inlet and Etsa syphon provide another outlet for the drainage of Minia Province to the Nile.

In the Gharaq basin, which is included in the Fayûm, a very difficult drainage question has become pressing. In consequence of the improvement of the Garaq Canal, as regards its cross section, slope and banks, which has been introduced by the last few years' work, the water supply to the Garaq depression has been considerably increased, and the necessity of means of drainage has made itself felt in those lands which have become water logged in consequence of obstructions formed to prevent the flow of drainage water to the lowest lands of the depression, where crops are planted. The water level, at the points where the Gharaq Canal divides into the branches which irrigate the depression, is R.L. 16·00. The lowest point of the depression is R.L. −1·50. The boundaries on all sides are high desert lands. Separated from the Gharaq basin by a ridge, whose crest is nowhere lower than R.L. 26·00, is the large depression known as the Wadi Rayyan, the bed of which

reaches a maximum depth of 40 metres below sea level. Thus the Wadi Rayyan affords a *possible* means of draining the Gharaq, but the channel to connect the two depressions, if carried through the lowest point of the ridge between them, would have a maximum depth of about 30 metres, and be of considerable length. The expense of making such a channel would be excessive, considering that the cultivated area in the Gharaq is only 14,000 acres.

Another *possible* means of drainage is to connect the Gharaq with the Wadi Nezlah main drainage line in the Fayûm by a channel cut through the intervening desert, and to pump up the drainage water into this channel to the height required by the water level in the drain at the point of connection. This is also not practical, on account of both the first cost and yearly expenditure.

The only practical solution of the question seems to be to imitate the conditions of irrigation and drainage in the Fayûm depression, in which Lake Qurûn serves as an evaporating surface for disposing of the drainage water which reaches it. The Gharaq depression is the Fayûm depression in miniature, and, had it always had a good supply of water, probably a lake would be now existing in its lowest part, into which the drainage would have flowed and been there evaporated. We have calculated that an evaporating area of between 2000 and 2500 acres would be sufficient. To carry out such a project it would be necessary for the Government to expropriate 2000 to 2500 acres of the lowest lying land, which unfortunately is mostly cultivated. Besides this about 30 kilometres of drains would have to be dug, costing about 3000*l.*"

In the Report for 1896, Mr. Wilson writes as follows :—

" The following account of the work done this year is taken from Mr. Webb's Report.

No new drains were made in Middle Egypt, the main drains are complete with the exception of the portion of the Muhit drain south of the Sabakhah Canal. An estimate amounting to 2500*l.* has been prepared for a combined syphon and bridge to carry the drainage under the Sabakhah Canal, and to connect the Muhit drains of the Asyut and Minia provinces. This syphon and bridge should be built when funds are available.

Other new drains are required, but the difficulty of disposing of the drainage water during the Nile flood under existing conditions would prevent their being of much use; moreover, the Daira Sanieh Administration and other proprietors have as yet shown no intention of making use of the existing drains by making branch drains leading to them: until they do so, it is not much use making more main drains.

The drainage of Middle Egypt will never be very satisfactory until pumps have been erected at the tails of the drains for lifting the drainage water during the flood time.

In clearances and maintenance 191,473 cubic metres of earthwork were executed at a cost of 2205*l.*, a regulator was built in the Western Muhit drain on the boundary of the Magaga and Feshn districts, and a drainage culvert was built under the Muhit bank of the tail of the Ehnasia el Khadra drain in the Beni-Suef Province to dispose of the drainage water after the flood.

In the Fayoum nine kilometres of new branches and extensions were made in

the Rodah drains: other new drains could not be made, as the necessary decrees for the expropriation of the land were not issued in time: they will be made this year.

Although benefit has resulted to the lands bordering the drains, no attempt has been made to excavate small field drains, and until this is done full benefit will not result. In clearances of drains, including the nine kilometres of new drains, 119,542 cubic metres of earthwork were executed at a cost of 1733*l.*

On repair of drainage culverts and syphons, 181*l.* were spent.

In the Gharak basin, drains are badly wanted, but, as pointed out in former reports, these cannot be made except by forming a lake in the lowest part of the basin, where the land is the best in the whole of the Gharak. The damage which would occur to this good land would be much greater than the benefit gained in the existing swamped area.

During 1896 the supply entering the Gharak was considerably reduced; masonry heads with iron shutters under lock and key were built for the irrigation outlets in the Bahr Gargaba, and the water given was cut down to the actual requirements of irrigation. The consequence is a marked improvement in the part of the Gharak immediately below this canal, and during a recent inspection the cultivators acknowledged this.

There is, however, no improvement in the other parts of the basin and, especially along the Awanat Canal, some of the land is terribly swamped. During the present year masonry heads with iron shutters will be built on the Baha Awanat in the same way as was done on the Bahr Gargaba last year.

I feel confident that the only satisfactory plan of dealing with the Gharak is to restrict the supply to the volume absolutely necessary for the irrigation, and to keep the water level in the canals as low as possible. The injury done to the low lands in the Fayum, owing to some canals being kept at a level high enough to irrigate the land bordering the desert, was pointed out in last year's Report.

The following table shows the levels of Lake Qarun on the 1st March for the last 13 years:—

Year	Level of Lake in metres Below Sea Level	Fall in Previous 12 Months
1885	39·80	unknown
1886	40·00	0·20
1887	40·38	0·38
1888	40·73	0·35
1889	41·17	0·44
1890	42·00	0·83
1891	42·78	0·78
1892	43·32	0·54
1893	43·78	0·46
1894	43·84	0·06
1895	44·17	0·33
1896	44·16	− 0·01(rise)
1897	44·27	0·11 "

During a careful examination of the perennially irrigated tracts of Upper Egypt in 1895 and 1896, I was much struck by the fact that great part of the country under such irrigation in the Minieh, Beni-Suef and Fayûm provinces had received very indifferent basin irrigation in the past, and in consequence consisted of very poor soil. For it must be remembered that when the red muddy waters of the Nile flood enter the basins, there is a tendency for all the heavy sand to drop first, and then the rich mud, and finally the very finest particles of mud with a large proportion of salts. Colonel Ross's improvement works had for their object the deposit of the mud as nearly uniformly as possible over the whole area, and the remedying of such defects in the basins south of Assiout. Well, these lands in Minieh, Beni-Suef and Fayûm, of which we are now speaking, had in old basin days received only the very worst kind of water, and the soil in consequence contained a large proportion of salts. Such lands were totally unfitted for perennial irrigation; what they wanted was a thorough overhauling of their basin irrigation, and a complete renewal with the rich red waters of the Nile flood. On the completion of the Ibrahimia Canal in 1874 these poor basin lands, covering over 100,000 acres in Upper Egypt out of a total of 580,000 acres, were converted into perennial lands. They were given heavy irrigation, called on to produce exhaustive crops, and had their spring level raised. On such tracts the deterioration of the soil has been so pronounced that the rents to-day are lower than what they were in basin days, and are steadily falling. Over 10,000 acres have been converted into salted plains. For such tracts there is no hope unless they are put under a thoroughly remodelled basin irrigation, and renewed with the rich red water of the Nile flood. Major Brown's spirited efforts to drain them have met with no success.

In 1893 an experiment was made in the conversion of poor basin land near Ahnessa into perennial land. By 1895 the deterioration was so marked that it was reconverted into basin land.

To the Ibrahimia Canal tracts the remarks made in the chapter on drainage about the flat lands in the Delta are directly applicable. When the soil is sandy, as it is opposite the southern halves of some of the basins, such as Itka and Tahanashâwi, the irrigation in summer and winter should be converted into lift. In the rich clay lands opposite the northern halves of the above basins, in the rich narrow strip from Minia to Samalut, in Beni-Suef, and in the well preserved lands everywhere, I think irrigation in summer and winter should be by weekly rotations, flush irrigation possibly in one week, and as low supply as possible in the next. The Daira Sania Administration, which owns the greater part by far of all this land, might with great advantage run its minor channels and water-courses north and south with the natural slope of the country, and not as at present, invariably east and west against the slope. These same minor

canals and watercourses should be kept full of water when irrigation is going on, and drained dry into the drainage cuts when not in use. At present they stand full of water well above the level of the country from year's end to year's end, doing nothing but harm. For that half of the broad strip between Samalût and Feshn which lies near the basins and which is decidedly deteriorating, additional drainage cuts are very badly needed. These drainage cuts should be supplemented by powerful escapes for excess water. For want of escapes, the canals stand stagnant for many months in the year. The escapes and drainage cuts should tail into the cross feeders, and have provided, as Mr. Wilson suggests, pumps for lifting the water when the Nile is too high to permit of free flow. No earthen dams of any kind should be allowed anywhere. The London policeman's rule of making everything move on should be rigidly adopted. For the salted and ruined lands at Salakos and the much deteriorated lands wherever they may be, the only remedy is a return to basin irrigation, but not the basin irrigation of the Yusufi Canal; the basin irrigation of the Girga Muderieh is what all this land needs.

In the Fayûm to-day it may be stated generally that all the low lands are sacrificed to the high lands. The rich high-lying plateaus traversed by the heads of the canals and their upper reaches, with plentiful water assured to them all the year round, with the valuable manure deposits of the ancient mounds, and with perfect drainage, are the delight of tourists, and typical of perennial irrigation at its best. But of the rest of the province it may be stated without any fear of contradiction that if the canals were doubled in section and rendered capable of carrying early and plentiful supplies of flood water, and if this water were utilised in irrigating the summer crops on the high plateaus, rice and maize on the secondary plateaus, and providing basin irrigation to the depressions and valleys, the province would be far richer than what it is to-day. Out of 329,000 acres 70,000 acres, or 21 per cent., are under summer crops, 170,000 acres, or 50 per cent., are under flood crops, and 250,000, or 75 per cent., are under winter crops. This proportion of summer crops is ridiculously small when it is considered that it dominates the irrigation question to-day and keeps the Fayûm back. As matters stand at present, the cultivators of the high lands run the small supplies of red water which the canals can carry through their fields, deprive them of their mud, run the waters back into the canals as the slopes in the Fayûm allow of it, and so convert the tail reaches of the canals into carriers of the worst kind of water. Such water, worse in many cases than drainage water, is all that the poor lands near the tails of the canals have for irrigation purposes. With capacious canals and copious supplies of red water proportional to the areas commanded these evils would be minimised, and the lands at the tails would be put under crop at the beginning of the flood and irrigated with red water, and thus be given a fresh lease of life.

Part of this great economy of red water is due to the fact that strenuous efforts have been made in recent years to lower the level of Lake Kurûn. I personally consider the lowering of the level of this lake a mistake while 70,000 acres of land lying *many* metres above the level of the lake are incapable of being cultivated because there is no water to irrigate them with. If the canals had the necessary supplies of water to ensure plentiful and early irrigation in July, August, September and October on the existing 329,000 acres of land in the province, the surplus water at the tails might be turned over the barren lands near the lake, and utilised to reclaim them with some chance of success. As matters stand at present the waters of the lake have been lowered some 5 metres during the last 14 years, great areas of waste land have been exposed, and as they are left barren and uncultivated they have in many places been turned into salt plains, over which the prevailing N.W. winds blow and carry the salts over the lands to the south and make them poorer than what they would have been if the level of the lake had not been interfered with. It must, moreover, be remembered that the fish of this lake are exceptionally good, and such a serious reduction of the volume of water in the lake must in the end be harmful to them.

It has been stated at the beginning of this chapter that the gross yield of the 252,000 acres on the Ibrahimia Canal is 2,640,000*l.*, and of the 329,000 acres in the Fayûm is 1,900,000*l.* These figures may be thus subdivided :—

For the Ibrahimia tracts :—

150,000 acres	at £14	= £2,100,000
40,000 "	at 8	= 320,000
30,000 "	at 5	= 150,000
12,000 "	at 3	= 40,000
20,000 "	at 1·5	= 30,000
252,000 acres	at £10·5	= £2,640,000

and for the Fayûm :—

50,000 acres	at £14	= £700,000
80,000 "	at 8	= 650,000
50,000 "	at 5	= 250,000
100,000 "	at 3	= 300,000
49,000 "	at 0	= 0
329,000 acres	at £6	= £1,900,000

If the patent defects in the irrigation systems were remedied, and in the Fayûm the summer supply guaranteed at 35 cubic metres per second, and the canals doubled in capacity for the flood supplies, the final figures for the two tracts would doubtless be as follows :—

The Ibrahimia tract would be :—

190,000 acres . . .	at £14 . . .	= £2,660,000
42,000 ,, . . .	at 8 . . .	= 336,000
20,000 ,, . . .	at 4 . . .	= 80,000
252,000 acres . . .	at £12 . . .	= £3,076,000

or a gain of 440,000*l.* per annum.

The Fayûm would be :—

100,000 acres . . .	at £14 . . .	= £1,400,000
180,000 ,, . . .	at 8 . . .	= 1,440,000
49,000 ,, . . .	at 4 . . .	= 200,000
329,000 acres . . .	at £10 . . .	= £3,040,000

or a gain of 1,140,000*l.* Truly there is a great field for any energetic and capable engineer in the Fayûm.

CHAPTER VI.

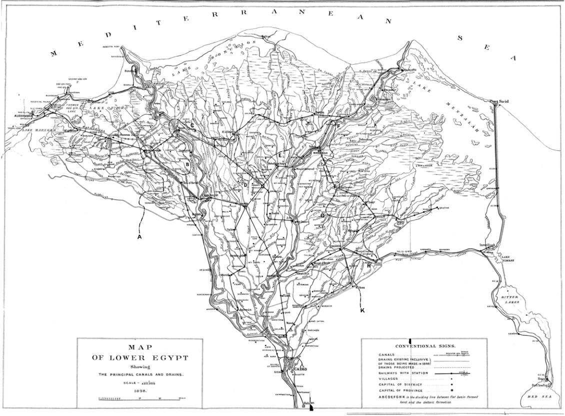
PERENNIAL IRRIGATION IN LOWER EGYPT.

Perennial irrigation explained—Formation of Lower Egypt—Difference between southern and northern halves—Mehemet Ali begins perennial irrigation in 1820—Comparison of summer discharges between earliest times and to-day—Discharges available in summer and utilised, 1874–1898—Quantity of water needed for the Delta in summer—Insufficiency of supply in four years out of twenty—Evil results of bad years in future—The three circles of irrigation—Principle on which the perennial canals were designed—The three seasons of the year—Numbers of pumping engines, masonry works, canals, &c.—Cost of maintenance of works—Prime cost of works—Difficulties of summer and flood irrigation from the same canals—Action taken by the Irrigation Department—Consequences—Main classes of land in the Delta—Principles on which canals should be maintained—Quantity of water needed for different classes of land—Necessity for keeping spring level low—Existing supply subdivided between the different classes of land—Future improvements which may be expected from improved system of drains and escapes—Discharges subdivided between the three circles—Duty of water in summer, flood and winter—The July discharges—Typical longitudinal and cross sections of canals—Tables of typical canals and regulators—Selections from Reports, 1884, 1885, 1886, 1888, low summer of 1889, 1890, 1891—The Rayah Behera—1892, 1893, 1894—The Katatbeh and Atfeh pumps—1896—Drainage.

Perennial irrigation,* as understood in Egypt to-day, is irrigation from canals which run the whole year round, as distinct from flood irrigation which is performed by canals running only in flood. In the chapter on flood irrigation it was stated that in the basin tracts there are not only basins irrigated as basins, but that the high Nile berms have been enclosed by banks and protected from the flood waters of the Nile, and thus enabled to produce crops all the year round. Such tracts are to all practical purposes perennially irrigated, as are also considerable areas in the basins which are sown with millets in summer and irrigated from permanent and temporary wells in the basins themselves after the winter crops have been reaped. But as no special canals have been provided for supplying perennial irrigation to such tracts, they are not closed as perennially irrigated lands for which the state provides perennial irrigation.

The Nile valley has been already described as a deltaic formation modified by basin irrigation into a series of terraces wherever the system of basin irrigation has been long practised. At the time of the Arab conquest

* In conjunction with this chapter read Appendix III., which contains an excellent monograph on the Behera province by Mr. Verschoyle, the Inspector of Irrigation. It unfortunately arrived after the book was printed, and could not be inserted in this chapter.


MEDITERRANEAN SEA
ALEXANDRIA
LAKE MAREOTIS
LAKE EDKU
LAKE BOORLOS
LAKE MENZALAH
Port Said
Ismailiyah
LAKE TIMSAH
BITTER LAKES
Suez
Port Tewfiq
RED SEA
CAIRO
A
B
C
D
E
F
G
H
K
MAP
OF LOWER EGYPT
Showing
THE PRINCIPAL CANALS AND DRAINS.
SCALE – 1/400,000
1898.
CONVENTIONAL SIGNS.
CANALS
DRAINS EXISTING INCLUSIVE OF THOSE BEING MADE IN 1898
DRAINS PROJECTED
RAILWAYS WITH STATION
VILLAGES
CAPITAL OF DISTRICT
CAPITAL OF PROVINCE
ABCDEFGHK is the dividing line between flat basin formed land, and the deltaic formation.

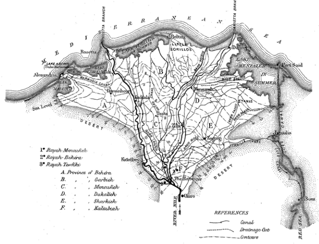
PLAN OF LOWER EGYPT.

PLATE 18

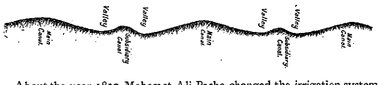
(CONTOURED)

Scale, $\frac{1}{1{\cdot}600{\cdot}000}$

Contours 1 metre apart, referred to Mean Sea.



the whole of Lower Egypt was under this system of irrigation and the whole country was under cultivation, a fact testified by the highly developed population of the country as recorded by historians, and by the countless remains of ancient towns and villages of considerable size, which now stand in the midst of vast desolations. Between A.D. 700 and A.D. 1800 the population had dwindled from 12,000,000 to 2,000,000 and irrigation had been abandoned over the greater part of the Delta. At the beginning of this century, basin irrigation was confined to an area upstream of a line roughly joining Delingat, Saft el Muluk, Damanhûr, Teh el Barud, Shibrakhet, Rahmania, Desuk, Sanhur il Medina, Nashart, Kalline, Simillay, Mehalla Kobra, Tira, Talkha, Mausura, Simbellawein, Safûr, Fakûs, Abûl-akhdar, Bordein and Bilbeis. Upstream of this line the country was more or less in terraces, while north of it the branches of the river and the natural canals flowed freely over the country and the regular deltaic formation was strongly developed, cultivation being confined to the banks of the canals. Beginning at the head of the Delta the country is absolutely flat, and as one goes northwards towards the line of villages and towns just given, the valleys between the canals begin at first to be scarcely visible, while as one approaches the line the depressions are more evident, but not more evident than in the larger basins of Upper Egypt. North of the line the depressions are very marked and become more so as one approaches the lakes. A cross section of this deltaic area would be somewhat as follows :—



About the year 1820, Mehemet Ali Pasha changed the irrigation system of Lower Egypt by excavating a number of deep perennial canals capable of discharging the low-level summer supply of the Nile. The presence of this water in the canals allowed of the cultivation of cotton during the summer, and thus introduced cotton on a large scale into Egypt. Mehemet Ali strengthened the dykes of the Nile and of the canals, which dykes now assumed a fresh importance as they protected the country from inundation; he stereotyped this new system of irrigation, as he did everything else he took in hand. If the embankments of the basins had been maintained, the basins might have been filled periodically on the old system, and Lower Egypt to-day would have been enjoying all the advantages of cotton cultivation together with those of basin irrigation. This, however, was not to be; the old basins were neglected, the embankments ploughed up, and now that rich mud deposit which constituted the wealth of Lower Egypt for thousands of years can no longer be secured to renovate the land.

The following information has been obtained from Linant Pasha's 'Memoirs.'

"The excavation of the grand summer canals necessitated 110,000,000 cubic metres of earthwork, representing an expenditure of 3,300,000*l.*

In a single year the Nile dykes were strengthened with 27,000,000 cubic metres of earthwork. The yearly clearances of the deep summer canals in Lower Egypt before the construction of the Barrages used to be 13,300,000 cubic metres, representing an expenditure of 530,000*l.* per annum. The measured discharges of the summer canals, before the Barrages were made, gave the amount of water entering the different provinces of Lower Egypt during an ordinary summer as follows:—

	cubic metres per second
Behera Province	11
Menoufia and Garbia provinces	35
Kalyubia, Sharkia and Dakalia	18
	64"

The Barrages were completed in 1865, but owing to accidents and difficulties they were not used till 1872, when the Rosetta branch Barrage was partially used and the Damietta branch Barrage not used at all. From this partial use, however, there resulted a great amelioration of supply, and the discharge entering the Delta canals was increased from 64 to 150 cubic metres per second. There were exceptional years like 1879 when both the Barrages were left open the whole year round and the discharge entering the canals never fell below 350 cubic metres per second, but a discharge of 150 cubic metres per second could ordinarily be counted on. In 1874 the discharge fell to 80 cubic metres per second, and in 1878 it fell to 100 cubic metres per second, but these were exceptionally low years. In 1884 both Barrages were used for the first time, and from then till 1891, when their repairs were completed, the water held up was 3 metres, and the discharge entering the canals rose to 300 cubic metres per second in an ordinary year, though there were years like 1889 when every drop in the Nile was utilised and yet the discharge fell to 200 cubic metres per second. It would do the same now, although the Barrages are repaired, if the discharge of the Nile were again to fall so low. Previous to 1884 the amount of silt clearance annually performed in Lower Egypt might have been put down as 16,000,000 cubic metres per year, costing the country 400,000*l.* Since 1884 the clearance may be put down as 8,500,000 cubic metres, costing the country 210,000*l.* per annum. Since 1891, the Barrages have been repaired and rendered capable of holding up 4 metres of water. The cost of silt clearance has not decreased, as drainage cuts are now maintained as well as canals, but the amount of water utilised has risen to 400 cubic metres per second in an ordinary year, though in 1892 it fell to 300 cubic metres per second, as that was all the water in the Nile. We may tabulate the preceding facts as follows:—

—	Ordinary Discharge	Maintenance Charges in £	Minimum Discharge possible	Area of Summer Crops Matured
	cubic metres per second		cubic metres per second	
Previous to 1872 .	64	530,000	0	250,000
1872 to 1883 . .	150	400,000	90	600,000
1884 to 1890 . .	300	210,000	200	1,200,000
1891 to 1898 . .	380	210,000	200	1,520,000

As each cubic metre of water in summer in Lower Egypt is capable of maturing 4000 acres of summer crops, we may state that previous to 1872 the summer crops covered 250,000 acres, between 1872 and 1883 they covered 600,000 acres, between 1884 and 1890 they covered 1,200,000 acres, and since 1891, 1,520,000; though with the aid of a perfect system of rotation this last figure has been raised to 1,700,000 acres in 1898.

The table on the next page gives the approximate discharges available at the Barrages and the discharges actually utilised since 1874. We are always face to face with the very uncomfortable fact that a year like 1878 or 1889 would result in a loss of 40 per cent. of the present summer crop of Lower Egypt, and years like 1890 and 1892 would result in a loss of 20 per cent. of the present crop.

In the Delta 1 cubic metre per second in summer suffices for the efficient irrigation of 4000 acres of cotton and dry crops, while the same quantity of water suffices for only 2200 acres of rice and wet crops. It may be accepted as a rule nowadays that half the cultivated area will be devoted to summer crops. Indeed, in many localities summer crops cover three-fourths of the total area, but this always results in so many acres being eventually thrown out of cultivation altogether that the proportion of 50 per cent. will work itself out. The proportion of rice to dry crops varies very considerably. In some districts half the area is under rice, but such tracts are limited. It may be safely assumed that with the quantities of water available for summer crops the proportion of rice to summer crops on the whole area irrigated will never exceed 10 per cent. unless the whole country is to be turned into marsh. Since the application of rotations (known as tâtils in Upper India) increases the area efficiently irrigated by fully 10 per cent., it will readily be seen that the area under rice may be neglected in considering the quantity of water needed for the whole area under summer crops. A supply of 1 cubic metre per 4000 acres will be acknowledged as sufficient by all irrigation officers for wholesale summer irrigation.

Now the cultivated land in the Delta is 3,430,000 acres, and the summer crops to be provided for may be considered as covering 1,715,000 acres, for which 430 cubic metres per second will be needed. Taking

the month of June, it will be seen that in the twenty-five years since 1874 there have been

2 years with a discharge of 200 cubic metres per second.
1 year " " 250 " "
3 years " " 300 " "
2 " " " 360 " "
17 " " " 430 cubic metres and over.

APPROXIMATE DISCHARGES AVAILABLE AT THE BARRAGE AND THE QUANTITIES UTILISED IN THE DELTA CANALS, IN CUBIC METERS PER SECOND.

Year	May		June		July 1 to 15	
	Available	Utilised	Available	Utilised	Available	Utilised
1874	280	90	350	90	800	250
1875	470	160	420	140	500	170
1876	570	180	490	140	900	300
1877	530	180	490	140	900	300
1878	250	120	200	90	300	200
1879	1500	350	1500	350	1700	400
1880	900	240	780	240	1000	300
1881	480	160	450	140	600	250
1882	380	150	300	120	370	200
1883	500	160	420	135	600	250
1884	720	300	650	300	700	300
1885	390	300	300	300	500	300
1886	450	300	450	300	700	300
1887	450	300	550	300	800	300
1888	470	300	420	300	550	300
1889	230	230	200	200	300	300
1890	270	270	250	250	400	300
1891	370	370	400	370	1100	460
1892	350	350	300	300	370	370
1893	1000	370	650	400	600	400
1894	450	370	450	370	700	370
1895	900	400	800	400	800	400
1896	730	370	680	380	800	410
1897	730	370	650	400	1200	450
1898	380	380	370	370	370	370

In 1889 there were 1,200,000 acres under crop, and the discharge of 200 cubic metres per second, though economised in every way, was quite inadequate. In the low lands great part of the rice perished, and the cotton crop everywhere was inferior. In 1892 there were 1,500,000 acres under crops, and the discharge of 300 cubic metres per second, though very skilfully handled, was inadequate. The area to-day is 1,700,000 acres. The six successive good years, 1893 to 1898, have given the agricultural

community a false idea of security; an idea of security which no irrigation officer of any knowledge partakes of for an instant. These very plentiful summer supplies of the Nile, and their continuous utilisation owing to the completion of the Barrage repairs, have immensely increased the area absolutely dependent on summer irrigation. In years of summer drought, like 1878 and 1889, there will be the greatest distress and loss of crop in those places which depend entirely on plentiful summer irrigation, and which are at present in no way protected against drought. The area liable to this new kind of summer drought has already assumed grave proportions and is on the increase. In cases of flood drought large areas are left unirrigated and produce no crops, but there is no waste of money spent on ploughing, watering, sowing and weeding crops which never come to maturity. With summer drought, on the other hand, there will be serious losses on these heads, and as, moreover, summer cultivation impoverishes the soil and renders it unfit for good flood and winter crops, the loss of the valuable summer crops will be feebly compensated for by poor flood and winter crops.

With these preliminary remarks we may proceed to consider in detail the existing system of irrigation in Lower Egypt. Lower Egypt is divided into three circles of irrigation. The Third Circle comprises the Province of Behêra, on the left bank of the Rosetta branch of the Nile, with its main canal the Rayah Behera. The Second Circle comprises the provinces of Menoufia and Garbia, between the two branches of the Nile, with its main canal the Rayah Menoufia. The First Circle comprises the provinces of Kalyubia, Sharkia and Dakalia, lying on the right of the Damietta branch of the Nile, with four main canals, the Ismailia Canal, the Sharkia and Basusia, and the Rayah Tewfiki. All these canals take their supply direct from the Nile from the upstream side of the Barrages at the heads of the two branches. The Barrages are considered capable of holding up 4 metres of water. As the floors of the Barrages are practically at R.L. 10·00 metres and the bed of the Nile is at the same level, the level to which the water can be maintained in low Nile, provided the supply is available in the Nile itself, is R.L. 14·00 metres. All the canals have regulating heads, and in this differ materially from the Ibrahimia Canal in Upper Egypt. These canals are at their heads about 7 metres below the level of the country, and as their maximum summer supply is from 3 to 4 metres in depth, the water surface is generally 3 to 4 metres below the level of the country at their heads. As, however, they gain on the country they can give flood irrigation at about 50 kilometres from their heads. The canals were originally designed to carry a supply in summer capable of irrigating one-third of the area commanded. To-day they carry a supply capable of irrigating half the area. The summer crops are cotton, rice, sugar cane, gardens and vegetables, while clover is irrigated up to the end of June.

The summer season really ends on the 1st of August, but as an early sown maize crop is far more valuable than a late sown one, every cultivator, who can, irrigates his land for maize in July, and increases considerably the difficulties of the irrigation officers. It is chiefly to prevent the people at the heads of the canals taking the whole of the water for their maize that the rotation system of irrigation has assumed such proportions. The summer is followed by the Nile or flood season. The flood crop of maize and sabaini rice is the staple of food for the whole agricultural population. During the flood, in addition to maize, the cotton, rice and sugar cane crops are irrigated and matured, and the fallow land is put under water. The water for flood irrigation is obtained both from the perennial canals and from separate flood canals. The perennial canals are filled so as to command the country, while the flood canals are shallow ones, capable of taking in only the flood supply with their heads about 2½ metres below the level of the country. The irrigation during flood is flush. The flood canals run through the flood months of August, September, October and November. The third season is the winter, when the crops are wheat, beans, barley, clover and vegetables.

As soon after the 10th July as water can be obtained the irrigation of land for maize sowing begins. The maize is sown up to the 10th September, but the late-sown crops are poor. The young plants are gradually thinned as they grow up, and provide green food for the cattle at this time of the year. For flood irrigation the earlier the Nile rises the better. The end of the flood is contemporaneous with the reaping of the maize crop, which is followed by a final heavy irrigation of the whole country, and the subsequent sowing of the wheat crop, after ploughing, and the clover generally without ploughing. Besides, therefore, the extra value of an early maize crop itself, it is very desirable that the final flood watering, which prepares the land for the winter crop sowing, should be given when the Nile water is high enough for flush irrigation. Since the Nile falls quickly after the 20th October, the sooner the maize crop is off the ground the less is the chance of there being any necessity to lift water by machinery for putting in the winter crop.

As soon as the flood irrigation is completed, the canals have the supplies at their heads very considerably reduced so that the whole country may be dried. This temporary reduction was first begun in 1887 and has been attended with the happiest results.

The comparative importance of the different seasons has been given in Chapter I. From it we extract the following :—

Taking the whole cultivated area of Lower Egypt as 3,430,000 acres, the summer crops cover nearly 50 per cent., or 1,674,000 acres, valued at 11,640,000*l.*; the flood crops cover 30 per cent. of the area, or 980,000 acres, valued at 3,710,000*l.*; and the winter crops cover 60 per cent. of the area, or

2,139,000 acres, valued at 8,125,000*l.* The total year's crop may be valued at 23,475,000*l.*, or 7*l.* per acre.

It may be interesting to see what Lower Egypt would have produced if it had been under flood irrigation. The first result would have been that the whole area of 3,930,000 acres would have been cultivated, as there would have been no lack of flood water. Turning to Chapter III., we see that 10 per cent. of the area would have been under summer crops, 15 per cent. under flood crops, and 95 per cent. under winter crops, and the gross yield at Lower Egypt rates would have been

	acres		
Summer	. 390,000 at £7	=	£2,750,000
Flood	. 590,000 at 3·9	=	2,300,000
Winter	3,740,000 at 3·8	=	14,210,000
Total . . .	3,930,000 at £4·8	=	£19,260,000

As the present yield is 23,475,000*l.*, there would have been a loss of 4,215,000*l.* per annum in gross yield, and about 2,200,000*l.* in renting values.

To accomplish the perennial irrigation there are employed 6973 kilometres of summer canals and 3037 kilometres of flood canals, while the flush irrigation is supplemented by 63,170 water wheels; 3250 portable engines representing 28,154 horse-power; 527 stationary engines representing 7852 horse-power. There are also 17,440 water wheels on wells in the fields. More than half of these water wheels are not used to-day.

The number of regulators is 943, and of syphons 126. The kilometres of canals is 10,010, of drains 2669, and of Nile banks 920.

The earthwork maintenance, as already stated, costs 210,000*l.* per annum, the masonry works maintenance costs 32,000*l.*; the flood protection works costs 22,000*l.*; pumping Lake Mareotis costs 9000*l.*, or a total for Lower Egypt of 273,000*l.* As the number of acres cultivated is 3,430,000*l.*, the cost of maintenance per acre is ·08*l.*

If we calculate approximatively the original cost of the Barrages at 4,000,000*l.*; of the canals at 6,600,000*l.*; of the masonry works at 2,200,000*l.*; of the Nile banks at 1,500,000*l.*; and the drains at 1,400,000*l.*, we arrive at a total of 15,700,000*l.* for 3,430,000 acres, or 4·6*l.* per acre.

Of the existing canals a few are on new alignments, most follow the traces of the old channels, and are in consequence very winding and crooked. They, however, command the country well and intercept no drainage. They are in this respect vastly superior to the artificial canals, which were, as a rule, laid out very badly. Plate XVIII. gives a contoured map of Lower Egypt, from which it will be seen that the longitudinal slope varies from $\frac{1}{10800}$ near the apex to $\frac{1}{30000}$, and even $\frac{1}{50000}$, near the lakes. When Mehemet Ali began cotton cultivation, he deepened these natural channels, and dug some new ones sufficiently deep to take in the low-level

summer water of the Nile. The yearly clearance of these canals entailed much labour on the country; and it was to obviate these difficulties that Mehemet Ali began the Barrages at the head of the delta proper in 1835, and had it not been for the corvée, or forced labour, he would have finished them. The presence of the corvée enabled the Government to dig the canals deep at their heads and dispense with the Barrages; and afterwards, when difficulties arose owing to a partial failure of the Rosetta branch Barrage, it seemed easier to the Government to keep on calling out the corvée than to face the problem of the Barrages, and definitely solve it. To these canals, deep only at their heads, Egyptian irrigation owed its difficulties. Canals meant to irrigate small tracts of land and needing during flood depths of from 2·50 to 3·00 metres of water, had depths of over 6 metres. They ran 1 metre deep in summer, and sufficed for the summer crop, which covered one-third the whole area commanded. During flood they irrigated the whole area, but had to run 6 metres deep in order to ensure flush irrigation along their entire lengths. The result was that regulators had to be built at intervals of 10 or 15 kilometres along the canals, and partially closed during flood to bring the water to the surface of the land. The checking of the velocity caused the Nile mud to settle in the beds of the canals in deposits of 2 metres and under, on hundreds of kilometres. This had to be removed yearly be the corvée at enormous cost. But this was only the beginning of evils. In spite of the closed regulators, and numerous other contrivances, the canals were so disproportionately large at their heads during flood that they sent down into the lower lands further north, where the canals had not only not been increased but had actually decreased in size owing to neglect, such an excessive volume of water that all the canals, escapes and drainage cuts were full to owerflowing with flood water, and were, in consequence, unable to perform their proper functions. These low lands during flood were divided into a number of islands surrounded by water at a high level. The natural consequence was that salt efflorescence was greatly on the increase in the small area under cultivation; while 1,000,000 acres capable of reclamation were maintained in a state of swamp.

These evils were aggravated by the fact that the corvée, who cleared the heads of the canals, had so much silt clearance to do that they never had time to reach the tails of the canals and clear them of weeds and rushes. Thus the canals were kept very deep and capacious at their heads and allowed to dwindle away at their tails. The first result of raising the water level at the Barrages was to allow of the beds of the canals at their heads being raised one metre. These canals consequently carried less water in flood, and an immediate relief was felt in the low lands near their tails. Still the relief was insufficient as the tails of the canals had been neglected for half a century. At this point the Irrigation Department seems to

have made two mistakes. These mistakes were due to the fact that most of the Inspectors of Irrigation had received their training in Upper India, where the summer crop is the important crop of the year, and where the Monsoon rains perform the irrigation in the rainy season which corresponds to the flood season here. So eager was the department to give flush irrigation in summer that it overlooked the fact that canals which give flush irrigation in summer when they carry one-third the supply, must of necessity either carry an insufficient supply in flood or carry it at a level which will cause heavy saturation of the soil. The wholesale reductions of the sections of canals in their middle reaches which immediately followed have had disastrous effects on the subsoil water level of large areas, and have rendered many canals quite unfit to perform their duties in the earlier stages of the flood. The other mistake which the department made was the conversion of the tail reaches of many of the canals into drains. It thus obtained cheap drains badly situated, but lost its flood escapes. Owing to the absence of these tail escapes, many canals have been turned into stagnant pools of water through eight months of the year.

An examination of the soil of the Delta will throw fresh light on this subject.

There are four main classes of land in the Delta. The first is the well-known dense black clay soil of a depth of over 6 or 7 metres. This soil is very rich and is especially suitable for cotton. It is injured very slowly by infiltration and saturation ; but once injured its reclamation is slow and stubborn. Such soil has not been anywhere injuriously affected by heavy irrigation, except where the canals have been run at a high level through twelve months of the year.

The next class of soil is a dense black clay of from 1 to 3 metres in depth, overlying sand. Previous to the heavy irrigation of recent years this land was everywhere studded with wells which were worked in winter and summer. Wherever canals running through winter and summer at a level higher than that of the country have been introduced into such tracts, the deterioration of the country has been very marked. Where, however, canals running at a level of about 2 metres below the surface in winter and summer have been introduced, the spring level has risen to that of the water in the canals, the wells have become more powerful, and the happiest results have been obtained. So plentiful is this subsoil water in places that a large proprietor has erected a 4 horse-power engine and 4-inch pump on a well on his estate which he works during the summer. This subsoil water is that immediately below the surface and intimately connected with the canals; it has nothing to do with the deep subsoil water which has been struck at Tanta and elsewhere.

The third class of soil is sandy clay. Such soil is especially suitable for maize and root crops, and where high lying it is very rich. The intro-

duction into such lands of canals running at a high level in winter and summer has meant the conversion of the country into marshy soil with a great accumulation of salts at the surface. In such soils the canals during winter and summer should be maintained below ground level.

The fourth class is pure sand, often indeed coarse desert sand, whose reclamation has been undertaken during the last few years. In such soils water should be lifted through the twelve months of the year if the neighbouring clay tracts which lie at a lower level are not to be converted into salted plains incapable of producing any crop at all.

It has been already stated that early-sown maize and rice produce twice the yield of late-sown maize and rice, and that the August waters of the Nile are particularly rich in fertilising mud. Any serious interference with the flow results in the silting up of the canal and the conversion of the red water into clear white water full of rushes and weeds.

With these facts before us, we may state that the most important season of the year is the flood season, when the whole of the summer crop is being not only irrigated but manured with the muddy waters of the Nile, when the whole of the maize and rice crops are being irrigated, and when the fallow land is being washed and warped. With the exception, therefore, of the heads of the main canals and feeders, whose bed-levels must be regulated to suit the summer level of the Nile, the first requirement of every canal is that it should be of such a section and depth that at the beginning of the flood in August it could carry enough water at a moderate height above the level of the country to quickly irrigate the whole of the land commanded. Any canal which needs rotations in August to enable it to carry water to its tail is quite inefficient. The next requirement of a canal is that the water should have a free and regular flow at a sufficient velocity throughout the flood, so as to be able to carry the muddy fertilising water of the flood to every field. Every canal, therefore, which is banked across and prevented from flowing freely and discharging into escapes or the lakes is faulty and harmful.

To prevent the water-logging of the soil and to keep the spring level well below the level of the country, it has been found convenient in certain localities to run the canals in alternate weeks, so that they act as drains in the intervening weeks, when they are practically closed. If the canals were of sufficient size it would be possible in this way to give flush irrigation on considerable reaches every alternate week without hurting the land.

When the water level of the canals throughout winter and summer is maintained below the surface of the ground, the soil is not salted, and is therefore capable of producing valuable maize crops, and the proprietors are not absolutely dependent on cotton. As, moreover, the water has to be raised throughout the summer for the cotton crop, the landed proprietors often prefer putting only one-third of their holdings under cotton, leaving

two-thirds for the flood maize. Since cotton requires 1 cubic metre per second per 4000 acres, and only one-third of the land is under cotton, a supply of 1 cubic metre per second suffices for 12,000 acres. Great part of Lower Egypt was in this condition previous to 1884.

When, on the contrary, the water level of the canals throughout winter and summer is maintained above the surface of the ground the spring level is high, and all but the high land salted at the surface. The maize crop is sensible of any salt in the soil as its roots are shallow, while cotton with its deep roots is not nearly so sensitive. And as, in addition, water can be obtained cheaply by free flow throughout the summer for the cotton crop, the landed proprietors prefer putting half their land under cotton and half under maize. As half the land is under cotton, 1 cubic metre per second in summer suffices for 8000 acres. This heavier irrigation and rising spring level causes the low-lying parts to become too salted to produce maize at all, and then maize is confined to the highest lands, while rice and cotton are sown in rotation in the lower lands. One cubic metre of water per second suffices for 2200 acres of rice, and on such land, if one-third is under maize, one-third under cotton, and one-third under rice, 1 cubic metre of water in summer suffices for only 5000 acres of land.

We have thus seen that by heavy and high-level irrigation throughout the year, tracts which were eminently prosperous and contented with 1 cubic metre of water per second in summer for every 12,000 acres, now demand 1 cubic metre of water per second in summer for every 5000 acres. Tens of thousands of acres which were irrigated from wells in summer and from canals in flood, are now irrigated from canals all the year round, make heavy demands on the scanty summer supply of the Nile, and are not one-half (in many cases not one-fifth) as prosperous as they were before. Over hundreds of thousands of acres where drainage cuts were unheard of and perfectly unnecessary, drains to-day are a prime necessity. The proprietors of such lands, with their urgent appeals for more water in summer and more drains, can only be compared to the two daughters of the horseleech. If, instead of listening to their appeals, canal officers were to boldly deepen and widen the canals and give the water a free flow down to the northern lakes, they would save the men from themselves and large tracts of country from the fate which has overtaken the Wady traversed by the high level Ismailiah Canal.

The demands for an ever-increasing supply of water and a perpetual extension of drainage cuts from these deteriorating tracts in the heart of the Delta, must be put on a very different footing from the demands for more drains and more water from the tracts further north which were salted or marsh, and which to-day are being reclaimed and improved at great expense on the part of their proprietors. These tracts will be fully considered in the chapter on Drainage and Land Reclamation.

It was stated at the beginning of this chapter that the cultivated area of Lower Egypt was 3,430,000 acres and the yield 23,475,000*l.* These figures may be subdivided as follows :—

Class I.	1,100,000 acres.	at £12	= £13,200,000
II.	700,000 "	at 8	= 5,600,000
III.	500,000 "	at 5	= 2,500,000
IV.	330,000 "	at 3	= 1,000,000
V.	800,000 "	at 1·5	= 1,200,000
Total	3,430,000 acres.	at £7	= £23,500,000

Of these 3,430,000 acres the first four classes alone really enjoy summer cultivation, the latter 800,000 are under reclamation, and in great part produce only flood rice and winter barley and clover over a part of the area. Class I., which is the best, needs only 1 cubic metre per second for 12,000 acres, Class II. needs 1 cubic metre per 8000 acres, and Classes III. and IV. need 1 cubic metre per 5000 acres. Class V. gets what is left. Working out these figures, we find

		cubic metres per second
Class I.	1,100,000 acres require in summer	90
II.	700,000 " "	90
III. and IV.	830,000 " "	170
or	2,630,000 acres require	350

Since the quantity of water utilised in summer is about 380 cubic metres per second, the remaining 800,000 acres receive at present 30 cubic metres per second. When developed they will need considerably more, or 150 cubic metres per second, which would raise the total to 500 cubic metres per second. But by that time let us hope that the levels of the canals will have been lowered, and then Class II. will run to Class I., and Classes III. and IV. to the land of Class II., and the whole 3,430,000 acres will only require 430 cubic metres per second in summer, thus made up :—

		cubic metres per second
Class I. and II.	1,800,000 acres	150
III. and IV.	830,000 "	120
V.	800,000 "	160
	3,430,000 acres	430

If this devoutly-to-be-wished consummation does ever come, the gross yield of Lower Egypt will run to 31,000,000*l.*, or a gain of over 7,000,000*l.* per annum

1,800,000 acres	at £12	= £21,600,000
830,000 "	at 8	= 6,640,000
800,000 "	at 4	= 3,200,000
3,430,000 acres	at £9·3	= £31,440,000

We have already stated that Lower Egypt is divided into three circles: the Third Circle, on the west of the Rosetta branch of the Nile, comprising the province of Behêra, with its principal feeder the Behêra feeder canal; the Second Circle, comprising the provinces of Menoufia and Garbia, between the Rosetta and Damietta branches of the Nile with the Menoufia feeder canal; and the First Circle, comprising the Kalyubia, Sharkia and Dakalia provinces with the Tewfiki feeder canal, the Ismailia Canal and the Sharkawia and Basusia Canals. The following table shows how these three circles have fared in the matter of summer supply since the introduction of summer irrigation, taking ordinary years as a basis of comparison:—

Period	Discharge, cubic metres per second			
	Third Circle	Second Circle	First Circle	Total
Previous to 1872	11	35	18	64
1872 to 1883	30	70	50	150
1884 to 1890	52	124	124	300
1891 to 1898	80	135	165	380

The cultivated area of the	Third Circle is	730,000 acres.
" "	Second Circle is	1,430,000 "
" "	First Circle is	1,270,000 "
	Total	3,430,000 acres.

If the discharge were distributed according to the area, the Third Circle would receive 21 per cent., or 80 cubic metres, the Second Circle would receive 160 cubic metres per second, or 42 per cent., and the First Circle 140 cubic metres, or 37 per cent. In other words, the Third Circle would receive what it does at present, and the First Circle would be reduced by 25 cubic metres per second, which would be given to the Second Circle. This distribution could be easily effected as all the canals have regulating heads. A fair subdivision of the final discharge of 430 cubic metres per second would be as follows:—

Third Circle	90 cubic metres per second.
Second Circle	180 " "
First Circle	160 " "
Total	430 cubic metres per second.

The following table gives the discharge and the duty for the three seasons of the year:—

LOWER EGYPT.

Season	Basis	Discharge in cubic metres per second	Area under Crop	Duty in acres per cubic metre per second
Summer . .	May 1 to June 15	380	1,670,000	4400
Flood . .	Aug. 15 to Nov. 1	1150	3,430,000	3000
Winter . .	Dec. 15 to March 1	300	2,140,000	7000
Year . .	.. ..	550	3,430,000	6000

Table XII. in Chapter II. gives the discharges of the canals through the twelve months of the year. The information is repeated here :—

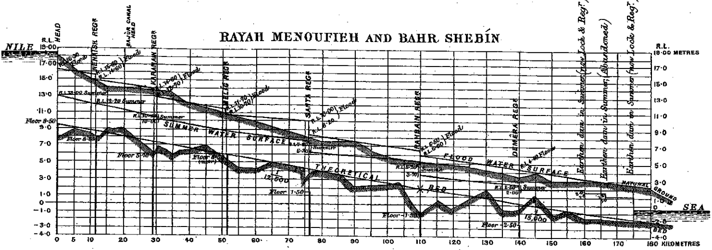
LOWER EGYPT IN AN AVERAGE YEAR.

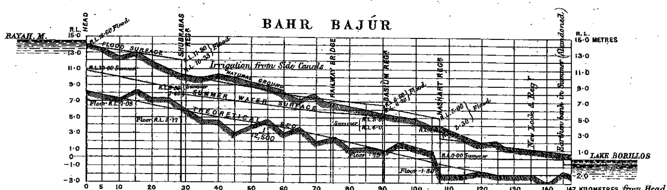
Month	Discharge of the Nile at Cairo, cubic metres per second	Discharge of the Delta Canals, cubic metres per second	Percentage of Total taken by Canals
January	1590	300	19
February	1120	300	27
March	800	300	37
April	550	300	54
May	430	350	80
June	410	410	100
July	1010	500	50
August	5280	1000	19
September	7200	1200	17
October	6860	1200	18
November	3740	500	14
December	2260	300	13
Year	2610	550	21

It will be seen that in an average year the only month in which the whole supply of the Nile is utilised is June. The water in July is as valuable as gold, and cannot be utilised as the Barrage cannot hold up more than 4 metres. To enable this July supply to be utilised, subsidiary Barrages are being built below the existing works to allow of a head of 5 metres on the two works. This matter will be discussed in the chapter on Barrages. I may, however, state here that in my opinion it would have been better to have spent this money on building a Barrage or weir on the Damietta branch at Zifta or Samaund, and discharging the water into the lower reaches of the canals near where it would have been needed, instead of carrying it at a high level on the top of the existing summer supply, and so helping to still further raise the spring level in the heart of the Delta.

Plates Nos. XIX. and XX. give typical longitudinal and cross sections of perennial canals in Lower Egypt. The six following tables give detailed information about the Canals and Regulators in Lower Egypt :—

TYPE LONGITUDINAL SECTIONS





Longitudinal Scale $\frac{1}{1,000,000}$ Vertical Scale $\frac{1}{400}$

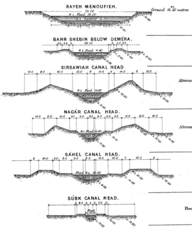
TABLE I.—MAIN CANALS, BEHÊRA PROVINCE.

Name of Canal	Length in kilometres	Bed Width in metres		Depth of Water			Slope in Flood	Velocity in Flood	Discharge, cubic metres per second			Remarks
		Head	Tail	Flood	Winter	Minimum Summer			Flood	Winter	Summer	
Rayah Behêra	41·0	26·00	20·00	6·00	3·20	3·40	$\frac{1}{12500}$	1·0	200×	78×	81×	Bed 20·0 to Kafr Eis, 18·00 below Kafr Eis. Flood discharge below Kafr Eis, 43. Summer discharge, 14.
Khatatbah	80·0	20·00	14·00	5·50	2·80	2·70	$\frac{1}{20000}$	0·90	215	..	..	
Nubariyah	81·0	10·00	3·00	3·00	1·70	1·50	$\frac{1}{20000}$	0·70	38×	15×	10×	
Ferhash	48·0	7·00	6·00	2·75	1·60	1·20	..	..	11	4	3	
Hager	72·0	6·00	2·00	2·25	1·50	0·75	..	..	7	3	1	Bed above Gimbaway Feeder, 4·0 width; anything up to 8·0 for last 25·00 kilos.
Abu Dyab	75·0	8·00	4·00	2·80	1·60	1·50	..	0·50	15×	5×	5×	
Khandak Gharbi	33·0	14·00	4·00	3·75	2·50	2·55	$\frac{1}{14286}$	0·60	31×	14×	14×	Bed width below Dinshal regulator = 6·00.
Khandak Sharki	45·0	8·00	17·00	3·50	2·40	2·55	$\frac{1}{13392}$	0·75	23×	12×	14×	Bed width increases from 8·0 to 17·0 after junction with Khandak Gharbi at Dinshal, and to 20·0 6·0 kilos. lower down
West Gannabiyah	13·0	6·00	6·00	3·20	1·90	1·80	$\frac{1}{20000}$	..	14	5	5	
Daheri	21·0	5·00	3·00	2·80	1·80	1·80	$\frac{1}{16666}$	..	9	4	4	
Sahel Markaz	26·0	13·00	10·00	3·40	2·60	1·90	$\frac{1}{16666}$	..	27	18	11	
Mahmudiyah	77·0	20·00	12·00	2·90	2·30	1·90	$\frac{1}{25000 + 50000}$	0·50×	55×	35×	37×	Discharges marked × are deduced from observations, the remainder from calculations.
Rosetta	40·0	8·00	3·00	2·20	1·60	2·15	$\frac{1}{16666}$	..	8	5	8	
Mehallet Keil	22·0	5·00	2·00	2·10	1·10	1·50	$\frac{1}{12500}$	..	5	1·5	3	

TABLE II.—MAIN REGULATORS, BEHERA PROVINCE.

Name of Canal	Name of Regulator	Distance from Head in kilometres	Number of Openings	Size of Openings		Height of Wing Wall	Depth of Water in Flood	R. L. of Floor	Remarks.
				Central	Rest				
Rayah Behêra	Head	0·000	3	..	4·10	8·00	5·90	10·60	Lock 33·0 × 8·0.
Ditto	Kilometre 21·0	21·000	3	..	5·00	7·00	5·90	8·90	Navigation opening 8·50.
Khatatbah	Burigat	17·000	5	4·00	2·95	9·50	6·50	3·50	Navigation opening in centre.
Ditto	Kafr Bulin	40·000	5	4·05	2·60	10·30	5·75	2·70	Ditto, floor 3·0 below true bed.
Ditto	Kafr Eis	51·000	3	4·00	2·95	6·00	4·75	4·25	No navigation opening.
Ditto	Kafr Awand	64·000	3	..	2·50	7·80	5·25	0·65	Floor 2·55 below true bed.
Ditto	Kafr Mustanad	76·000	3	..	2·50	7·10	5·20	0·50	Floor 1·80 below true bed.
Sahel Markaz	Rahmania	8·000	4	..	2·50	5·10	4·00	1·65	
Rosetta	Edfina	14·000	1	..	2·50	2·95	2·20	0·23	
Nubarieh	Dist	10·000	6	..	2·50	5·21	3·40	5·40	
Ditto	Kilo. 46·00	46·000	4	..	2·50	4·35	..	3·65	
Ditto	Kilo. 60·00	60·000	3	..	2·50	4·35	..	3·01	
Ferhash	Furniyah	30·000	1·00	..	1·5	3·00	2·50	3·85	
Hager	Hoche Issa	42·000	2·00	..	1·6	3·40	1·85	0·10	Floor 0·85 below true bed.
Abu Dyab	Saft el Enab	12·00	2·00	..	2·90	4·25	4·00		
Ditto	Ramsis	18·00	2	..	2·90	4·25	4·00	4·80	
Khandak Gharbi	Dinshal	27·00	1	..	2·50	4·00	3·00	2·70	
Ditto	Umm el Henash	34·00	1	..	1·50	3·50	2·80	2·20	
Mahmudieh	Head	0·00	2	12·00	7·80	4·00	3·20	−·50 and −1·00	Two locks with regulating timbers.
Ditto	Kafr Dawar	45·00	3	..	2·20	4·50	3·20	ō·50	A lock 58·0 × 12·00.

TYPE SECTIONS OF EGYPTIAN CANALS



DETAILS OF DISCHARGES.

	Season	Bed Width (mean)	Area of Cross Section in Sq. metres	Slope	Mean Velocity metres p. sec.	Discharge in C. metres per second.	
	Flood	55·0	340·00	1/30,000	.90	320	
	Summ.r	55·0	150·00	1/12,000	.70	120	
	Flood	22·00	90·00	1/15,000	.70	60	
	Summ.r	22·0	30·00	1/100,000	.10	2	
Alternative weeks	Flood	8·0	60·00	1/21,000	.50	30	
	Flood	8·0	60·00	1/12,000	.65	40	
	Summ.r	8·0	10·00	1/12,000	.33	3	
Alternative weeks	Flood	6·0	40·00	1/27,000	.45	18	
	Flood	6·0	40·00	1/14,000	.60	24	
	Summ.r	6·0	10·00	1/12,000	.33	3	
	Flood	8·0	60·00	1/26,000	.50	29	
	Summ.r	8·0	10·00	1/12,000	.33	3	
Flood Canal	Flood	4·0	11·00	1/20,000	.30	3	

TABLE III.—MAIN CANALS, MENOUFIA AND GARBIA.

Name of Canal	Length in kilometres	Bed Width in metres		Depth of Water			Slope in Flood	Velocity in Flood	Discharge, cubic metres, per second			Remarks
		Head	Tail	Flood	Winter	Summer			Flood	Winter	Summer	
Rayah Menoufia	23	55	55	6·5	4·5	3·5	$\frac{1}{18000}$	·90	420	160	120	Navigable.
Bahr Shebín	186	50	35	6·5	4·5	3·0	$\frac{1}{15000}$	·90	270	92	64	Navigable between Regulators.
Bahr Bajûr	96	25	25	5·0	2·5	2·0	$\frac{1}{10000}$	·80	64	29	20	Ditto.
Nagár	27	6	6	4·0	1·0	1·0	$\frac{1}{22000}$	·45	11	2·5	2·5	Silts; being provided with extra escapes.
Nenaiah	39	6	6	4·0	2·0	1·0	$\frac{1}{14500}$	·65	18	9	4·5	
Sirsâwiah	85	8	3	4·0	1·5	1·0	$\frac{1}{18000}$	·45	20	7	4	Silts slightly.
Atf	59	10	6	4·5	1·5	1·0	$\frac{1}{20000}$	·50	23	8	4	
Khadrawia	35	10	6	4·5	1·5	1·0	$\frac{1}{22000}$	·50	23	8	4	Silts occasionally.
Sahel	141	8	8	4·0	1·5	1·0	$\frac{1}{14000}$	·50	17	6	3	
Séf	62	8	6	4·0	1·5	1·0	$\frac{1}{20000}$	·50	17	8	4	
Batanunia	51	10	6	4·5	1·5	1·0	,,	·50	29	12	5	
Kâsad	96	10	8	5·0	3·0	2·0	,,	·70	41	23	12	Navigable between Regulators.
Gafaria	70	10	8	3·0	2·0	1·0	$\frac{1}{22000}$	·55	14	9	7	
Malha	87	30	60	3·0	2·0	1·0	$\frac{1}{20000}$	·65	41	21	5	Navigable in flood and winter.
Tíra	70	30	4	3·0	2·0	1·0	$\frac{1}{12000}$	·70	46	12	4	Ditto.
Belkâs	28	15	8	3·0	2·0	1·0	$\frac{1}{18000}$	·65	23	5	5	Ditto.
Kuddâba	67	7	4	4·5	3·5	3·3	$\frac{1}{16000}$	·65	18	7	6	
Kôtoni	50	10	8	4·0	3·2	3·0	$\frac{1}{12000}$	·65	18	9	7	
Saldi	38	30	15	2·5	2·0	1·0	$\frac{1}{30000}$	·40	41	6	3	Navigable in flood and winter.

TABLE IV.—REGULATORS, MENOUFIA AND GARBIA.

Name of Canal	Name of Regulator	Distance from Head in kilometres	No. of Openings	Size of Openings		R.L. of Floor	R. L. of Surface Water				R. L. of Ground	Remarks
							Flood		Summer			
				Central	Others		Up-stream	Down-stream	Up-stream	Down-stream		
				metres	metres	metres	metres	metres	metres	metres	metres	
Rayah Menoufia	Head	0	7	4·17	4·17	10·00	18·50	16·30	13·00	13·00	17·00	Lock, 50 × 8 × 2.
"	Nenaiah	11	10	4·00	4·00	8·60	15·80	14·80	12·20	12·20	15·40	" 35 × 8 × 2.
Bahr Shebín . .	Karanain	29	10	5·00	5·00	5·70	14·00	12·90	10·80	10·20	14·10	" 17·5 × 7 × 2.
" . .	Melig	52	10	3·00	3·00	5·70	12·00	11·00	9·00	9·00	11·30	" 35 × 7 × 2.
" . .	Santa	76	11	5·16	2·28	1·50	10·00	8·20	7·80	6·30	8·40	" 50 × 8 × 2.
" . .	Rahbein	110	9	5·10	2·30	−1·30	6·50	6·00	5·20	3·70	5·20	
" . .	Demera	139	7	4·67	2·08	−2·90	4·40	4·40	2·50	2·00	3·40	
" . .	Basendila	160	3	3·00	3·00	−1·00	3·25	2·50	2·00	1·50	3·60	" 24 × 6 × 2.
" . .	Bouna	179	3	3·00	3·00	−2·00	1·50	0·50	1·00	−·60	2·30	" 24 × 6 × 2.
Bahr Bajur . .	Head	0	5	4·00	3·00	7·08	14·40	13·50	10·90	10·30	13·90	" 50 × 8 × 2.
" . .	Shubrabas	29	5	4·00	3·00	5·13	11·90	10·30	7·80	7·70	10·90	" 50 × 8 × 2.
" . .	Bassium	91	8	3·00	3·00	0·98	6·60	5·50	5·50	4·20	5·40	
" . .	Nashart	108	5	. .	. .	−1·79	3·55	2·00	4·00	·50	3·50	"
" . .	Sidi Salem	135	3	3·00	3·00	−2·00	1·30	0·50	1·30	−·60	1·20	" 24 × 6 × 2, flood.
Bahr Saidi . .	Head	0	3	3·00	3·00	+ ·50	5·00	3·00	. .	1·50	3·70	" 24 × 6 × 1·5.
" . .	Osman	23	2	3·00	3·00	+ ·15	2·50	1·70	1·50	1·00	2·00	
Birshams Canal .	Head	0	7	5·50	2·10	7·06	16·80	14·30	10·50	10·50	14·30	
Bahr Mallah . .	Head	0	3	3·15	2·30	1·31	7·50	5·00	5·50	4·00	5·70	" 17·5 × 6 × 2.
" . .	Tombara	25	2	3·00	3·00	0·00	3·80	3·00	2·80	1·80	4·30	" 17·5 × 6 × 2.
" . .	Halafi	56	2	3·00	3·00	−1·40	1·60	1·20	0·60	0·00	1·20	
Bahr Tira . .	Head	6½	7	4·75	2·15	−0·60	5·40	5·20	3·00	3·00	3·90	
" . .	Abshan	29	5	3·00	3·00	+1·50	3·80	3·80	2·80	2·00	3·20	" 17·5 × 6 × 2.
" . .	Hamoul	48	2	3·00	3·00	−0·25	2·20	2·20	1·20	1·20	1·40	" 17·5 × 6 × 2.
Kased Canal . .	Head	0	3	3·80	2·25	4·33	11·80	10·20	9·00	8·30	11·30	
" . .	Ganzur	11	3	3·55	2·55	3·60	9·80	9·20	7·50	7·50	9·30	
" . .	Tanta	23	2	. .	4·75	4·10	8·70	8·70	6·90	6·90	8·00	

TABLE V.—MAIN CANALS, KALYUBIA, SHARKIA AND DAKALIA.

Name of Canal	Length in kilometres	Bed Width in metres		Bed	Depth of Water in metres			Discharge, cubic metres per second			Remarks
		Head	Tail		Flood	Summer	Winter	Flood	Winter	Summer	
Rayah Tewfiki	65	26	18	9·50	6·00	4·0	4·10	210	110	110	To Mit Ghamr, 3 locks, 50 × 8.
Ismayilia	225	14	8	10·30	5·70	3·20	3·70	11	29	50	To Suez, 13 locks, 35 × 8·5 × 2·0.
Sharkawia	30	10	7	11·00	6·10	2·65	2·50	76	17	14	To head of Khalili Canal.
Shibini	46	8	8	9·50	5·00	2·75	3·00	23	12	16	
Khalili	30	6	6	10·50	3·25	1·70	1·60	17	12	9	
Bassussia	24	8	6	11·60	5·50	2·00	1·70	35	10	8	
Kumbathin	12	..	..	10·60	3·90	2·00	2·0	..	..	..	
Filfila	22	3	3	10·60	3·50	2·00	2·0	..	..	..	
Bahr Moes	88	15	6	8·00	4·50	2·00	1·60	87	23	18	Lock at head, 8·0 × 50·0.
Buhia	53	10	4	6·00	3·60	1·50	1·5	29	12	12	
Umm Salama	35	5	5	5·00	2·50	1·10	1·10	..	..	..	
Bahr Tanah	23	6	4	1·50	3·50	2·50	2·50	..	..	..	
Mansuria	42	14	10	5·50	3·50	1·50	1·30	104	36	32	To Menzala, lock at head.
Bahr Sagair	71	12	4	1·50	3·85	2·30	1·50	48	35	17	
Faraskur	56	10	3	1·83	2·80	2·20	2·20	26	8	8	
Abul Akhdar	41	10	10	10·00	4·00	2·90	2·90	..	..	..	
Bahr Faqus	33	13	8	5·70	2·8	1·3	1·30	..	..	..	

TABLE VI.

REGULATORS, KALYUBIA, SHARKIA AND DAKALIA.

Names of Canals	Name of Regulators	Distance from Head in kilometres	No. of Opening	Size of Opening		Height of Abutment	Depth of Water in Flood	R.L. of Floor or Sill	Remarks
				Central	Others				
				metres	metres	metres	met.	metres	
Rayyah Taufiki	Head	0	6	5·00	5·00	9·50	6·10	9·50	U.S. Nile.
	Gangara	37	7	3·00	3·00	6·34	5·30	7·10	
	Mit Ghamr	65	7	3·00	3·00	4·50	3·50	5·50	
Mansuria	Head	0	3	3·30	2·28	5·20	3·50	5·50	U.S. Nile.
	Sanayta	17·5	7	3·00	3·00	5·70	3·90	3·60	
Shark. Faraskur	Head	0	3	3·00	3·00	5·17	2·77	1·83	U.S. Mansuria.
Buhia	Head	0	4	3·00	3·00	2·60	3·60	6·00	U.S. Rayyah Taufiki.
	Mit Mushin	6	2	2·60	2·60	7·28	5·40	3·30	
	Hamama	30	3	1·80	1·80	3·50	1·80	3·50	
Umm Salama	Head	0	2	3·00	3·00	4·00	2·50	5·00	U.S. Mansuria.
Bahr Saghir	Kulangil	0	3	3·00	3·00	5·67	4·72	·83	U.S. Mansuria.
Bahr Moes	Head	0	7	3·00	3·00	6·50	5·30	7·00	U.S. Rayyah Taufiki.
	Tessa	45	9	2·45	2·35	4·70	2·70	6·00	
	Safra	67	5	3·00	2·50	4·00	2·70	3·50	
	Kafr Sagr	82	4	2·50	2·50	3·80	3·20	2·20	
	Tal Rak	99	2	3·00	3·00	3·90	3·40	0·50	
Bahr Mashtul	Head	0	3	2·60	2·60	5·60	4·50	4·53	U.S. Bahr Moes.
Bassussia	Head	0	3	3·65	1·90	6·75	5·50	11·60	U.S. Nile.
Sharkawia	Head	0	4	6·75	2·40	9·30	6·10	11·00	U.S. Nile.
	Hanzania	17	3	3·40	2·25	6·35	5·75	10·15	
Ismayilia	Head	0	2	2·75	2·75	9·40	4·50	10·30	U.S. Nile.
	Seriakos	12·535	2	2·75	2·75	11·00	4·02	9·18	
	Bilbeis	49·235	2	2·75	2·75	9·00	2·91	7·69	
	Kassassin	93·660	2	2·75	2·75	5·40	..	5·64	
	Upstream lock	127·412	1	8·5	..	3·77	2·65	4·35	
	Downstream lock	128·659	1	8·5	..	2·58	2·24	1·26	
Suez branch	Nefisha H. lock	0	1	8·5	..	6·95	1·60	4·60	U.S. Ismayilia Canal.
	Serapium	16·193	1	8·5	..	3·00	1·75	4·05	
	Genefa	41·650	1	8·5	..	3·00	1·71	3·39	
	Shalloufa	68·350	1	8·5	..	3·00	1·65	2·74	
	Suez lock	90·043	1	8·5	..	3·20	1·97	1·63	

The following selections from the different Reports will elucidate the working of the irrigation system of Lower Egypt.

The first is a selection from the Report of 1884, by Sir Colin Scott-Moncrieff :—

"In the Behêra Province more than any other the policy has been developed of supplying the canals by powerful steam pumps, one establishment having worked for many years at Atfeh where the Mahmudieh Canal has its head in the Nile, the other worked for the first time in 1882 at Khatatbeh, about 100 kilometres further up the river. These pumps are the property of the Behêra Irrigation Society, and Government entered on an engagement to utilise them up to the year 1915, purchasing, up to the beginning of 1885, during the months of Low Nile up to three millions cubic metres per diem, and after that up to five millions cubic metres. When this contract was made there was of course no idea of bringing into use the Nile Barrage. We can only accept it as it exists, and try to make the best use of it.

During 1884 the Khatatbeh pumps worked from 1st May to 9th August, delivering on an average 12 cubic metres per second. The Atfeh pumps worked from 17th March to 15th August, delivering 16 cubic metres per second.

The rise of the Nile was unusually late last year—or these pumps would have ceased earlier—Government paid to the Society 27,426*l.* for this water supply."

In the Report for 1885, Sir Colin Scott-Moncrieff writes as follows :—

"The two great canals of the Sharkia Province are the Sharkawieh and the Bahr-Moes. The former rising above the Barrage has its supply thus ensured to it. The head of the Bahr Moes is below Benha and therefore uninfluenced by the Barrage, and it was chiefly to keep it supplied that the temporary dam across the Nile was erected.

The idea of throwing such a bar across the Nile was due to Mr. Willcocks, and it was an idea received in the country with great doubt, not to say alarm. It was confidently asserted that we should not be able to remove it before the Nile rose, and an inundation was predicted. It was begun early in April and held up at the maximum 1·07 metre.

It was 430 metres long, consisted of 16,000 cubic metres of stone and burnt brick and cost 2520*l.* By the middle of July it had been removed and formed not the slightest impediment to the river during flood. The effect of this dam was to give abundance of water to the district N.E. of Zigazag, where previously at this season there had been drought.

For the first time this year the Bahr-Moes was cleared by dredgers instead of by Corvée labour. The dredgers were not well adapted for their work, which was therefore costly and not very good, but the Corvée was spared labour, and Zigazag enjoyed an unbroken water supply throughout the whole year.

Our efforts to divert the water from the river into the canals by the use of the Barrage had an effect we did not anticipate. The water at Khatatbeh on the Rosetta branch fell so low that the pumps could not work; and as their level had been fixed by Government it was necessary to throw a light dam across the river to hold

up the water surface half a metre. As the low water had stopped all navigation, stones could not be brought down for use on this dam. It was made therefore by running out earthen banks from both sides, leaving a space of 70 metres in the middle, which was closed by sand bags. The cost was 1426*l.*, upwards of 16,500 bags of earth were used, and the desired object was effected.

A more serious difficulty arose from the influx of salt water, which unless controlled would have reached as far as the Atfeh pumps which supply the Mahmudieh Canal and the city of Alexandria. This difficulty showed itself early in April, and to prevent it Mr. Foster threw a dam over the river at Mehallet el Amir. It was composed of earth, and was carried out in water from 2 to 5 metres deep with the help of about 400 piles for a distance of 180 metres on the one side and 250 metres on the other, leaving an opening of about 70 metres in the centre. This dam cost £7536. It was maintained with much difficulty, the north wind blowing heavy waves against it. Usually the water flowed outwards through the contracted opening, but on several occasions while there was a distinct under current outwards of fresh water Mr. Foster found a surface current of salt water inwards, and for 204 hours altogether the Atfeh pumps were unable to work.

As in Gharbieh there was serious injury inflicted in Behêra also on those who irrigated downstream of the Mehallet el Amir dam. Altogether 5042 acres of rice were reported as injured, and a remission of 3979*l.* taxation was made.

Another serious consideration was the supply of drinking water to the old town of Rosetta. Like other Egyptian towns Rosetta possesses a number of fine cisterns under the houses, which are intended to be filled during High Nile. But they had been neglected, and when the fresh water ceased to come down the river it was necessary to take prompt measures. First a daily train of tank carriages was organised from Alexandria, and afterwards a regular boat service was established on the river, barges being filled with fresh water daily at the dam and towed by a steam tug down to Rosetta. This water service answered well and cost altogether 539*l.* While all this was in operation we availed ourselves of the services of Mr. Cornish, C.M.G., the well-known Director of the Alexandria water works, who most kindly volunteered to superintend an experimental boring at Rosetta for an Artesian well. The boring was carried to a depth of 153 feet but without success, and as the cost was already 252*l.* it was thought better to go no further.

I have thus thought it right to enter fully into the injury effected towards the two mouths of the Nile by the abstraction of the water. I have shown that the river was exceptionally low, and that our machinery for distributing the water was defective. With it all 8967 acres of rice land were reported to have suffered. Even assuming that this was below the mark, I believe I can state fearlessly that at least ten times the area derived great benefit, and that a very large tract, especially in Sharkieh, received water during summer which had never received it before.

As the Nile rose in August an experiment was made. It had been customary to close the Rayah Behêra entirely at this season and admit water into Behêra by the head of the Khatatbeh Canal. In 1885 the Rayah Behêra ran continuously throughout the floods. The result was good, in so far that early muddy water was given to the great benefit of the maize crop; but the force of the current cutting between the sandy banks of the canal about 20 kilometres from the head tended to make it wider and shallower to an extent that has caused us much trouble since. No effort should

be spared to make the Rayah Behêra the one source of supply for the province, but it will require considerable outlay and trouble before the upper portion is brought into a satisfactory condition."

The next selection is from Sir Colin's Report for 1886 :—

"The system of throwing temporary dams across the river which had been successfully tried in 1885 was continued and extended in 1886. On the Rosetta branch a dam was placed, as in 1885, downstream of the Khatatbeh pumps, commenced at the end of March and finished in the the middle of April at the cost of 2609*l.* The object of this was to hold up the water surface sufficiently to allow of the Khatatbeh pumps working.

The Mehallat el Amir dam was renewed a few miles above Rosetta to keep in the fresh water of the river, and still more to exclude the salt water of the sea which would otherwise have been pumped into the Mahmoudieh Canal. In 1885 this dam cost 7556*l.* In 1886 it cost as much as 11,022*l.*, a very heavy charge. In 1885 the dam was not closed right across the river, but an opening was left in the middle. In 1886 the river was entirely barred, and a carriage might have driven across it. On one side the water was perfectly fresh, on the other quite salt. This dam was begun on the 17th February, an earthen bank being thrown out a distance of 332 metres on one side and 304 metres on the other, the average depth of water being about 4 metres. This left an opening of 70 metres in the middle, across which a rough stone and brick weir was thrown. On 12th May the dam was closed. The rising flood carried away the dam in July, but the brick portion remained and would have formed a danger to the navigation had not a boat been moored at each end to mark its position with lights at night. Mr. Foster hopes to make the dam much cheaper in 1887, but I fear it will be impossible to dispense with it altogether until we have so rearranged the irrigation system of Behêra as to render us independent of the pumps at Atfeh. When the canals of Behêra can be fed entirely from the Rayah Behêra and Katatbeh it will be no longer necessary to keep out the salt water.

On the Damietta branch the dam built last year below the head of the Sahel Canal and Bahr-Moes was renewed (see page 7 of last year's Report). Its total length was 200 metres. In 1885 16,000 cubic metres of stone and brick were used in this work. In 1886 it only required an addition of 3706 cubic metres, which cost 581*l.* It was used this year to hold up 1·05 metre of water, which was enough for the supply of these two canals.

M. Garstin constructed another very successful dam over the river below the head of the Mansurieh and Om Salama canals. This proved of the greatest help to the irrigation of Dakahlieh and successfully held up ·63 metres of water. It was 156 metres long, connected in the right flank to the high river's edge by an earthen insubmersible embankment 137 metres long. The dam consisted of a rough stone platform 18 metres wide and about 2·8 metres high above bed level. The top was 4 metres above mean sea level. On this was built a crest wall 1·41 metre high. It was finished by 17th May, contained 6387 metres of stone and brick, and cost 3945*l.* It was easily removed by the end of July.

One other dam or *sadd* was placed across the river 5 kilometres downstream of Damietta, in order to keep out the salt water and to enable the low lands

between the city and the sea to be irrigated by a new canal (termed the Esbet el Bourg Canal).

This dam was made of sand and earth, faced on the northern side with bricks to protect it from the action of the waves. It was laid in water about 4 metres deep for a length of 400 metres, which was found enough, for it left an opening sufficiently contracted to ensure a constant flow outwards. It cost 2585*l*."

The following selections are from Sir Colin Scott-Moncrieff's Report for 1888 :—

"The 'Sadds' or closure embankments across the tails of the canals in Gharbieh to prevent the water running to waste in the sea were made and removed as follows—

On the Bahr	Mahalla:	made	1st January,	removed	3rd September
"	Tira	"	15th February,	"	31st August
"	Shibin	"	15th January,	"	31st "
"	Nashart	"	25th March	"	18th "

The late date of the removals of these 'Sadds' was due to the deficient Nile flood.

The summer was a hot dry one, and it was with great difficulty that Mr. Willcocks managed to keep the great cotton crop alive. On the 15th May he commenced the rotation of irrigation by closing the canals for seven days out of twenty-one. From the 20th June he could only keep them running for seven days out of fourteen. From the 5th July to the 11th August the canals were closed for fourteen days out of twenty-one. This was fatal to the rice crops, the interest of which it was necessary to sacrifice in order to keep the cotton crop alive.

The most important thing to be done for the irrigation of Behêra is the restoration of the Rayah Behêra, or canal taken from above the Barrage, to enable it to carry water sufficient for the irrigation of the province, and to render it independent of the costly pumping at Atfeh and Khatatbeh. There is no other canal in Egypt so unsatisfactory and so discouraging. Large sums have been spent on it year by year and yet it is until now practically valueless. It would have probably been easier and cheaper to have made an entirely new canal than to have gone on as we have done, trying to restore to usefulness a very bad canal.

In 1885 and 1886 the unfortunate experiment was made of running this canal during Nile flood, in the hope that a scour would be produced and the bed deepened. Exactly the contrary took place. The sandy banks fell in, and the bed widened and was choked by a deposit of sand. Some of this was cleared away early in 1887, but the great flood of that year burst through its banks and again a great sand deposit was formed. All the dredging done since then has failed to bring the canal to a proper level, and the irrigation of Behêra is really effected by the pumping stations.

But in spite of all discouragement the Rayah Behêrah is being put into order. I am hopeful that after 1st May, 1890, we shall be able to dispense with the Khatatbeh pumps, and in 1891 that Behêra will derive its irrigation from this canal and no further pumping will be required.

The pumps worked as follows throughout the year 1888.

—	Commenced Pumping	Finished Pumping	Days Working	Mean Discharge per second
				cubic metres
Atfeh . .	25th November,'87	25th August, 1888	276	20
Khatatbeh .	8th February, 1888	12th " "	185	27
Total discharge per second				47

The amount paid (see Appendix A, VII.) to the Behêra Irrigation Society for this water was 61,255*l.* It would have been well to have begun the Khatatbeh pumps at an earlier date. As it was, during the cotton crop and until the Nile rose the pumps were daily supplying 61 cubic metres per second, a larger volume than was ever furnished before.

The dredging ceased and the Rayah Behêra was opened on 1st June, but it only added 6 cubic metres to the discharge. The system of giving irrigation by rotation on different canals was practised again this year in Behêra, and met with the same unreasoning opposition. I trust now, however, the agricultural classes have learned that this system is not one of choice, but of absolute necessity if the present area of irrigation is to be maintained in summer."

The next selection is from Colonel Ross's Report for 1889, one of the worst summer supplies of this century.

"The following discharges were taken by Mr. Reid, on May 16, at the Barrage, and those of July 7th were deduced from them.

Date	Rosetta Branch		Damietta Branch		Rayyah Menufiya		Total Discharge, cubic metres per second
	Gauge	Discharge	Gauge	Discharge	Gauge	Discharge	
May 16 .	10·00	32	11·00	70	12·90	92	194
July 7 .	9·60	24	10·70	58	12·65	83	165

The discharges of July 7 were practically the minimum of the year. If we add 35 cubic metres for the supply of the canals taking off between Cairo and the Barrage we have a minimum of 200 cubic metres per second passing Cairo.

If we compare the very low summer Nile of 1878, which closely resembles the year 1889, we find the cotton exported from Alexandria:—

1878, 1,680,595 kantars or cwt.

1889, 3,200,000, of which perhaps 200,000 kantars were from Upper Egypt.

This magnificent increase has been obtained by utilising the whole amount of water in the river by holding it up at the Barrage and the 'Sadds' (earth and stone dams) across the river. The great personal efforts of the Engineering Staff aided by the civil authorities also contributed to this magnificent result. It must be borne in

mind also that the yield of 1878 per acre was greater than that of 1889 owing to the existence of the cotton worm in greatly increased numbers in 1889. The area of 1889 is probably four times that of 1878.

In the First Circle (the country east of the Damietta branch) the scarcity of water was decidedly obviated by the very skilful maintenance by Mr. Garstin of the dams and bars of stone and earth across the Nile. The Damietta branch was ponded up by the dam at Mit Ghamr to such an extent that the river to the north was so low at Mansourah that children could walk across it. The dams of Benha and Mit Ghamhr have held up as follows as maximum heads.

	1888	1889
Benha dam	1·50	2·25
Mit Ghamr dam	1·43	3·20

These enormous maximum heads were maintained for nearly all July.

The Damietta dam was fully closed this year, but somewhat too late to prevent a rush of salt water for about 50 kilometres. The cost and details of these dams were as follows:—

Name	Stone	Earth-work	Cotton Sacks	Sand Bags	Cotton Shuting	Rope Bags	—	Cost
	cubic metres	cubic metres	No.	No.	No.	No.	cubic metres	£
Benha	8991	1113	50	..	..	20	3830	6690
Mit Ghamr	7796	17529	2712	4878	2355	..	..	6493
Damietta	*A forfait* and dredging							4700

Full rotations were put in force as follows:—

Name	Date of First Stopping Engines	Date of First Stopping Canals
Kaliubiyah	June 21	March 26
Sharkiyah	July 6	July 2
Dakahliyah	June 17	July 1

In the latter part of the time of scarcity very severe rotations had to be put on. Mr. Willcocks notes as follows for the Second Circle.

Where the rotation system did not fail and one irrigation per twenty days was secured, the cotton gave magnificent yields. The yield was better than what it was on the Nile where there was no limit to the irrigation. Crops irrigated once in thirty days suffered slightly, irrigated once in forty days suffered appreciably, and irrigated once in sixty days preserved their foliage, but gave no yield.

Long canals such as the Sahel and the Khadrawiyah were divided into reaches of some 35 or 40 kilometres each and fed from new feeders. If this were possible everywhere there would be no necessity to stop engines except on the main canals.

The Qâsid with its great length and innumerable branches had 10 days' closure

of its minor canal heads and stoppage of its engines alternately. This was fairly successful. The minor canals were all deepened and widened to allow of this. The same was done on the Gafariyah and Bahr Shebin minor canals. The Bahr Saidi was fed through the Om Yusuf drain. By this means it got every cubic metre sent down to it, as there are no machines in the drain, and 25 difficult kilometres were got over.

The three canals where irrigation failed were the Nenaïah, Sirsawia, and the Bahr Sef. These canals are between 90 and 50 kilometres long each, and traverse the heart of the small-holdings tracts, where water-wheels abound. Stoppage of engines without stoppage of water-wheels has been proved to be of no avail; and in 1890 it has been proposed to stop every kind of irrigation as well as the engines. The sheikhs have unanimously given their consent on condition that whenever the engines are stopped for ten days, the wheels, &c. will be stopped for six and run for fourteen days. If the governor of the province can enforce this rotation, irrigation will be easy.

In the Third Circle, the water pumped from Khatatbah and Atfah was distributed most carefully by rotation commencing from the 17th of February. In this Circle the people have, since the necessity of sending application for water wheels was abolished, built large numbers of these wheels, and although this is a gratifying sign of the existence of capital, it has somewhat thrown the canal system out of gear, more especially on the Rosetta Canal, and the result has been that the small quantity of water available for the Rosetta Canal frequently failed to reach Rosetta. Up to the present, native opinion has been very averse to imposing rotations on water-wheels, but as they have multiplied so much it will be necessary in the future to impose it, more especially on canals where there are large towns dependent on the supply reaching the end of the canal.

The Rosetta dam was made this year for 9170*l.* The cost of the dam since 1886 has been—

1886	1887	1888	1889
£11,384 .	. £10,649 .	. £10,840 .	. £9,170

Mr. Foster has paid great attention to cutting the dam on the rising Nile so as to prevent the scouring of deep holes, and the result is that the *à forfait* price in 1890 is only 8000*l.*

The Khatatbah dam, principally made of stone, is necessary to maintain the river to contract level at the Khatatbah pumps. The head on it is not great and it is always thoroughly in hand. The comparative cost is this:—

1885	1886	1877	1888	1889
£1426	£2608	£2329	£818	£1656

The amount of water passing through the Rosetta branch in the low Nile of June and July was 18 cubic metres per second, and the amount drawn out of it by the Khatatbah and Atfeh pumps was 41 cubic metres. Hence the balance, or 23 cubic metres per second, was drawn from the filtration water of the river. The filtration water is salter than the Nile and is therefore not so fit for use. The Atfeh pumps so exhausted the supply of fresh water that the Nile at Atfeh (60 kilometres from the Rosetta dam) was a still water pond held above the sea level by the dam,

and which had a film of fresh water on it only 40 centimetres deep floating on the top of a deep layer of salt water, so salt as to be quite unfit for irrigation and drinking purposes. Had the low supply lasted one week longer, we should have been compelled to deprive the Central and Eastern Provinces of a portion of their water to sweeten this great pond from which Alexandria draws its drinking water, as it was falling at the rate of 2 centimetres a day, and the water-wheels of the Atfeh pumps could not have worked with a further fall of 30 centimetres."

It will be seen from a perusal of the above that the minimum discharge of the Nile was 200 cubic metres per second, and that the infiltration water utilised on the Rosetta branch was 23 cubic metres per second; as the same quantity was utilised on the Damietta branch, the total discharge utilised was 246 cubic metres per second, of which 82 per cent. was Nile water and 18 per cent. was infiltration water. The importance of the Nile branches as sources of supply is very evident.

The next selection is from Colonel Ross's Report for 1890, another low year.

"The discharges of the river at Cairo can only be deduced from the sum of the discharges of the canals taking off below Cairo.

The water at Cairo in low Niles is practically a still water pond.

Mr. Roux, attached to the Second Circle, took the following discharges on 16th and 17th June. On these days the gauge readings were:—

		June 16	June 17
Cairo		8·02	8·03
Shubrah		13·07	13·07
Barrage gauges	Upstream Rosetta Branch	12·85	12·85
	Downstream Damietta Branch	10·08	10·08
	Downstream Rayyah Taufiki	12·84	12·84
	Downstream Rayyah Menufiyah	12·72	12·72
	Downstream Rayyah Beherah	12·82	12·82
	Downstream Rosetta Branch	10·00	9·99

The discharges were:

		Cubic metres per second	
First Circle above Cairo	Ismailiyah Canal	29·0	
	Sharkawiyah Canal	10·5	
	Basusiyah Canal	3·0	
		42·5	
Rayyah	Taufiki	62·5	105
	Menufiyah		93
	Behera		29
Total			227*

Mr. Garstin has had his canal discharges taken during the year every fortnight, and the following table shows the diminution of supply and the slow rise of the supply owing to the rising Nile.

It must be understood that there is generally no pressure before May 1st.

* Allowing for infiltration water the discharge utilised must have been 275 cubic metres per second.

DISCHARGES IN CUBIC METRES PER SECOND.

Date		Ismailiyah	Sharkawiyah	Basusiyah	Rayyah Taufik
May	1st	34	10	4	70
	15th	32	10	4	64
June	1st	29	10	5	65
	15th	29	9	3	62
July	1st	37	10	4	70
	15th	51	18	11	99
August	1st	62	19	11	87
	15th	..	87	76	220

The distribution of the water was enforced by the most praiseworthy exertion of all the staff. The mudirs and their subordinate staff gave great assistance, and it may be safely said that without the help of the civil officers, irrigation in summer with a short supply of water would be impossible.

The combination of mudir and inspector has had the very best results, and the Ministry of the Interior were ever ready to check any indifference on the part of the provincial authorities.

The area of crop matured of all kinds was very large, and fortunately the cotton worm was not so prevalent as usual. The result has been a very large increase of cotton: 4,100,000 kantars or cwt. against 3,200,000 of the year before.

The Rosetta branch dam at the mouth of the Nile was maintained with great success by the Third Circle and rendered it possible to use the Atfeh pumps. The dam at the mouth of the Damietta branch was however abandoned after mature consideration as being injurious to the flow of the branch in flood. The Rayyah Taufiki on the right and the Bahr Shibin on the left with their riverain branches supplied the water fresh and wholesome, though not in so great abundance as could be wished. The difficulties of disconnecting the Nile bank engines from their intakes on the river was met by cutting channels to their intakes from the riverain canal. The Government warned the landowners in February that there would not be sufficient water for rice and that the river would be salt. They disregarded the warning and did not make the necessary connections. The result was a loss of crop from salt water.

I am most certainly of opinion that this dam should not be permitted in future, as its yearly renewal will seriously disturb the regimen of the lower reaches of the Damietta Branch.

The following notes are from the Reports of the Inspectors showing in each Circle the most noteworthy points.

The First Circle was completely revolutionised by the opening of the Râyyah Taufiki, the new canal taking off from above the Barrage and feeding the Bahr Mues, Sâhil Canal, Um-Salamah Canal, Mansûrîyah Canal, and the Sharkâwîyah-Fâraskûr. This fine canal now supplies all the northern part of the Province of Sharkiyah and all the Province of Dakahliyah.

The difficulties of distributing water along the long line of 175 kilometres of main canal were much aggravated by the very inefficient state of the minor canals taking from it. So much money has been spent in making the Rayyah Taufiki

itself that the Public Works Ministry found it impossible in the interest of other Circles to allot further sums for internal distribution, and the result was an excess of water in some parts of the system and great drought in others. A beginning was made in great haste by making new or repairing old heads of branch canals in the main line, but this was not enough. The entire system has far too many canals of distribution. They are all dug down to an abnormally low level, in order to get a little summer water in each on the old system, and when the Rayyah Taufiki filled the old trunk canals to a depth of 2 metres more than before, it was almost impossible to check the outflow of water through the new heads. It thus came about that the lower parts of the system were almost in the same state as before, the water not being raised practically.

The water also in the lower reaches of the Damietta branch being salt owing to the earthen dam (sadd) not having been made below Damietta, was not available for irrigation, and consequently the Trunk Canal parallel to the river had to irrigate much land usually irrigated direct from the river.

Rotations to distribute the water were in force as follows:—

Mudiriyahs	Stoppage of Engines	Stoppage of Sakiyahs	Stoppage of Canals
Kaliubiyah	12th June—16th July	Nil	7th June—16th July
Sharkiyah	18th ,, —27th ,,	23rd July—27th July (locally)	23rd ,, —27th ,,
Dakahliyah	10th ,, —4th August	5th July—22nd July	10th ,, —28th ,,

These dates mean that in the period indicated the rotation periods of flow and closure were observed. Before and after these periods, water was freely taken by everbody.

The mudir of Kaliubiyah and the chief engineer worked very hard indeed, both being frequently out for days patrolling and keeping their subordinates up to the mark.

In the Second Circle which comprises the country lying between the two branches of the Nilè, the water supply was very short owing to the low supply in the river and owing to the abolition of the earthen dam in the Damietta mouth of the Nile. Much of the area irrigated by engines from the Nile direct was supplied by the riverain canals taking from the Bahr Shebîn. Thus the water entering the head of the province had to do more duty than last year. Mr. Willcocks introduced several internal changes which were productive of much benefit.

They are the following, extracted from his Report:—

'The tail of the Kasid Canal, which was always in difficulties, was supplemented by the new Safti Canal, 20 kilometres in length, taking out of the Baguriyah Canal.

'The Nanâiyah and Sirsawiyah Canals, which failed completely in 1889, were supplemented by the Bahr Faraoniyah and proved successes. The Bahr Faraoniyah was opened from Rayyah Menufiyah with signal advantages both to navigation and irrigation. The mudir of Menufiyah, Nashaat Pasha, threw himself heartily into this work and collected the necessary funds from the interested parties.

'The Bahr Sêf, another feeble canal, was supplemented from the Batunaniyah Canal, and did its irrigation without a single complaint for the first time in its history I think. Here again the mudir, Nashaat Pasha, was invaluable. As to the

irrigation on the two Nile branches near the sea, it is my opinion that the Rosetta dam should always be put in, as the Rosetta branch is deepening and scouring its bed and no fears need be entertained for it. The time to do away with this dam will come when the proposed reservoirs in the "Birriyah" * are a success, if they ever are a success. The Damietta branch, on the other hand, should never be dammed at its mouth, except under exceptional circumstances.'

The distribution of water by rotation on the ten days' shift has become permanently fixed in this Circle on a ten days' shift, i.e. the canals and engines running ten days and leaving off for ten days. The discharge entering the Rayyah Menufiyah does not vary much between March and Midsummer. The excessive demand which springs up in June and July is principally caused by the great heat and by the commencement of the maize crop."

From Colonel Ross's Report for 1891 the following selection has been taken :—

"The Second Circle does not give any comparative gauges, but makes the following remarks on rotations, showing the desirability of always enforcing rotations, so that the machinery may be in full work before the pressure comes. The pressure mentioned is of course the pressure for maize sowings.

Mr. Clifton writes :—'Towards the end of July there were many complaints in Gharbieh for water which came very suddenly. This arose mainly through the ordinary ten-day rotations not having been enforced, owing to the plentiful supply. The result was that Menufiyah had taken advantage of this water and by July 20th had sown nearly all the maize, whereas Gharbieh had not got over the difficulties of summer irrigation.

'From this year's experience, I should be strongly in favour of enforcing the canal rotations from the beginning, say May 10th, and not waiting until there is a general want and then having to shut off the water in some places where it is really wanted, so as to give it to others in rotation. Through the acquiescence of the mudirs, this stress was got over smoothly, and we were fortunate in having Menufiyah well satisfied before the rotations were put on. The mudirs were most energetic in the destruction of the locusts which at one time seriously threatened the cotton crop; owing to their exertions, the damage done was very trifling.'"

In the Report for 1891 Mr. Foster writes as follows on the Behêra feeder canal or Rayah Behêra.

"Now that the Rayyah Beherah is fulfilling at least part of what it was designed to do, viz. passage of summer water, it is a suitable opportunity for recording its history since 1884, when I first had charge of it.

It takes out of the west bank of the Nile above the Barrage, having an almost due westerly course for 9 kilometres, on which distance it crosses the last of the chain of Gizeh basins. At the 9th kilometre it enters the desert at the point where the Libyan hills splay out towards the west. It follows the curve of these hills at an almost uniform distance of one thousand metres till it joins the Khatatbah at kilometre 41. With the exception of a small area of cultivated land on kilometres 31 to 36 between the Nile and the canal, it traverses pure desert on the last 32 kilometres.

* The Birriyah is the low land on the edge of the lakes in the north of the Delta.

With the exception of the cultivated area above mentioned, some few sycamore trees and a few tufts of tall grass on kilometre 26, these 32 kilometres were absolutely devoid of any kind of verdure.

The space between the canal and the Libyan hills forms a sort of valley. Borings on this side showed clay at varying depths below the sandy surface. Sycamore trees growing in the desert near Beni-Salamah must have their roots in clay. These facts lead me to suppose that at one time the whole area between the hills and the Nile was cultivated, and that it had been lost by ceasing to flood it in the basin system.

Probably when the Rayyah Beherah was made, which was some 28 years ago, the thickness of sand overlying the clay was not so great as it is now; but that the banks were to a great extent desert sand is known from the fact that after using it for the passage of flood water it was abandoned as a flood canal and used only for Summer supply.

Annually some 20,000 men (Corvée) were employed for 25 to 30 days in clearing out sand, which they invariably piled close to the water's edge and which naturally fell in again. To this constant quantity to be cleaned was added sand drifted in during the year, so that the Rayyah Beherah was either steadily closing up or the number of men employed in cleaning was annually increasing.

During flood, stone dams were made at the head and at kilometre 8. Another dam (earthen) was made at kilometre 27 and the reach filled by leakage through the upper dam. This was done partly to divide the head and partly for the irrigation of those villages near the Nile mentioned above.

The result of the 500,000 men's work above mentioned was to produce a discharge of less than 6 cubic metres per second with the Barrage gauge at 12·50 metres.

Such was the state of the canal in 1884 when I first knew it. It had not been cleared that year nor was it cleared in 1885.

It was decided to try it during the flood of 1885. The result showed that the sandy banks would not resist the strong current of high Nile without some form of protection. Banks were eroded and the bed raised to a very serious extent. But an experimental spur made during the flood showed how easily the current could be guided. This led to the erection of a number of wooden spurs in 1886. They cost comparatively little, as the timber was found in a stack of rubbish at the Barrage.

Again this year, flood water was allowed to pass down the canal. Where spurs existed and were not turned or carried away, little damage was done either in erosion of banks or rising of the bed, but elsewhere the destruction was as great, if not worse than in 1885.

This proved beyond all doubt that very expensive protecting works were necessary before the canal would be fit to carry flood or indeed any depth of water. A large number of spurs were therefore made in 1887. Sacks filled with sand were used and a few were made of stone. Many of the wooden spurs remained. But both these and the sand bag spurs were destroyed by Bedouins, who brought herds of camels during the night and carried off wholesale timber and sacks. The mudiriyah gave no assistance, notwithstanding repeated applications were made.

A proposal was made to clear the canal of silt by scour during flood. With this object in view, an escape was made into the Nile at kilometre 36 and a narrow but fairly deep channel opened in the canal itself to give the water a lead;

but owing to this latter work not having been completed in time the trial was not made, and instead the canal was closed with an earthen dam at kilometre 7 and another at kilometre 27 in the old spot.

The flood of 1887 was excessively high. It breached in the Rayyah Beherah on kilometre 16, but was turned back through an old canal near 27 kilometre dam. This breach did a great deal of damage on kilometres 16 and 17, but it proved that the sand bag spurs did well and that sand in the bed would scour. Nevertheless it was decided to abandon altogether the thought of cleaning by scour and to depend entirely on hand and machinery labour. Since 1887, flood water has never entered the canal, and all the clearance done has been in accordance with the above decision.

In 1886, a successful attempt had been made to grow grass which was transplanted from the tufts found on kilometre 26. It was found to grow with very little water. More was planted in 1887, and in the same year a large number of willow cuttings were put in at high flood level. Of these a certain number died, but the remainder have proved a useful store on which to draw for other cuttings. While the foregoing was taking place inside the canal, experiments were being made outside in the western desert.

In 1885, I expressed my belief in a Report, that the movement of sand would not be stopped unless the desert could be flooded. For this purpose I proposed making banks across the valley joining the Rayyah Beherah with the desert hills, but this proposal was not accepted until later on (in 1887).

The Iswid Basin is protected at kilometre 11 by a bank known as the Gisr-el-Rimal between the canal and the desert hills. This bank used to be guarded with religious care, as it was thought that a breach would result in the entire flooding of the Beherah Province. Notwithstanding the care taken, a breach occurred in 1885, shortly before discharge of the basin commenced.

Although I much doubted that any damage would occur, but on the contrary believed that good would result, I allowed the breach to be closed, but not before a considerable quantity of water had found its way through. The result was as I expected. The desert absorbed such a large quantity of water that the flood did not extend beyond the 27th kilometre. No sooner had water begun to dry up than small plants showed above ground. This was all I wanted to prove. In 1886, I cut this bank just before the time of basin discharge, and left it open, thereby securing a large volume of water which travelled to Khatatbah, doing no harm, but on the contrary, much good.

In 1887, the Abu-Ghalib and Beni-Salamah banks (kilometres 19 and 32) were made between the canal bank and the desert hills. And in order to secure water as early as possible, a canal was dug from the Nikla escape on kilometre 6 to a point a short way beyond the Rimal bank.

Water was carried past these banks through channels in high ground on the slope of the desert hills. A rough weir composed of sand bags permitted, to a certain extent, control of the quantity allowed to pass forward.

Sand screens were tried as an experiment in 1886 and 1887, but having been badly placed and constructed were not very successful. Nevertheless, such as they were, they proved that drift sand could be arrested.

This brings events down to the winter of 1887–88, when it was decided to make an extensive attempt to reclaim the Rayyah Beherah.

As before stated, the actual cleaning of the canal was to be done by hand and machinery. The good done by flooding and the advantage of spurs, grass plantation and sand screens were recognised. It was decided to extend all these operations. The restoration of the Rayyah Beherah may be considered to have commenced in the beginning of 1888. It remains now to show what has been done since, and the results obtained. It was decided that the canal should be given a section of bed width of 20 metres; level of bed at head sluice R. L. 10·00; slope in bed 65 millimetres per kilometre $\frac{1}{15384}$, and it was with this end in view that all operations were carried on. I should say also, that in disposing of silt, sufficient space has been given to permit of the bed width being increased to 26 metres and the slope to 75 millimetres per kilometre.

In 1888, the quantity removed by machine and hand labour was 390,729 cubic metres. Work was suspended during flood and commenced in October of that year. From this time until May 1891, dredging was continued throughout the year. Machines were imprisoned during flood between dams, where they worked in still water. These dams were cut in 1889 on 1st June, in 1890 on 1st April, and again on 12th December for the supply of water for irrigation. (I may here note in passing that the Khatatbah pump ceased to work on the 10th April, 1890, and those at Atfeh on the 10th August of the same year.) By the end of May 1891, the section towards which we had been working had been secured with the exception of a few kilometres (14 to 20) where erosion of banks caused by the employment of large dredgers in flowing water had caused the bed to rise. The clearing of this lump was postponed until after flood, and was nearly removed by the end of the year.

	cubic metres
The total quantity of cubes dredged from October 1888 to May 1891 was 3,162,000 cubic metres, which, added to those worked early in 1888, makes a total of . .	3,552,729
Add dredging of the unfinished lump on kilometres 14 to 20, being done in 1892	200,000
Grand total . .	3,752,729

Besides the above dredging, the removal of stone dams at the head and at kilometre 8 were continued, the latter having been completed and the former nearly so.

The centre line was worked from the railway which is carried on the left bank. In this way, lines have been made straight and curves true. Where the canal was too wide (in some places it was as much as 70 metres) dredged stuff was deposited in such a manner as to reduce the section. Where it was the required width or less, all out-turn was discharged outside the bank.

With the exception of a short length of 100 metres, all sand has been put on the right or eastern bank, prevailing winds being from the west. On the first 9 kilometres, silt has been carried out into the Nile or discharged into slurry pits on either bank.

Finding cheap materials for spur making, such as old timber and sacks, to be a failure, sanction was given for the manufacture of bricks for the purpose. Stone would have been used, but the depth of water was insufficient to float the smallest Nile boat.

Sufficient clay had been deposited during the flood of 1885 and 1886 to supply

what was required fo rbrick making. Bricks made were 40 × 20 × 10 centimetres, and were built into spurs for 45 piastres per cubic metre. Transport was effected by rafts constructed by the contractor at his own expense. A very large number of spurs (upwards of 200) were built in 1888 between kilometres 11 and 32. In 1889 and 1890 a few more were made, partly of stone and partly from brick dug out of buried portions of old spurs, and the old ones repaired. In 1891, another lot was made between kilometres 32 and 39, and a number of smaller ones wherever there were any signs of erosion. On the straight, spurs are placed opposite each other every 200 metres. In certain places they are closer. On flat curves they are placed at every 100 metres on the outside, and every 200 on the inside bank. On sharp curves at every 50 metres on outside and from 100 to 200 metres apart on the inside. Small spurs to put a stop to local erosion are placed from 30 to 50 metres apart. The total number of spurs existing is 475 on kilometres 9 to 40, or an average of 12 per kilometre.

It has been stated above that the plantation of grass and willows was tried in 1886 and 1887, and it has been carried on since without intermission. The left-hand bank was practically completed by the end of 1889. On the right, plantation has followed dredging, and at the present time, though not as thick as on the left, grass covers the bank from below summer level to a considerable height above flood level. During 1889 and subsequent floods, grass has been planted in the western district along the foot of the hills, around hillocks and alongside the railway. A staff of men varying from 20 to 50 according to the season have been thus employed. In addition to grass, a number of acacia and other trees have been planted, and are, for the most part, doing well. The tufts of grass, 'Buss Hagna,' mentioned as found on kilometre 26, are the parents of nearly all that now exists. Other kinds have been tried, the 'Hagna' with success, but 'Buss Baladi' not so. 'Buss Hagna,' which is different to 'Hagna,' will only grow in loose sand. Even a small admixture of clay kills it. Hagna grows very thick and has a multitude of roots. A little trouble has been given by Burdi grass, which grows in deep water. This is the grass which chokes drains. All these grasses seed once a year. The fact that grass is growing in the desert where none has been planted, shows that the seed is blown about by the wind and germinates.

Prior to 1888, 11 kilometres, and in 1888 11 kilometres of screens were erected, 22 metres from the railway on the desert side. This distance was fixed by the Railway Administration. In 1889, spaces omitted the year before were filled up and a second row erected in some of the worst places. By the end of this year. screens extended in a continuous line from kilometre 10 to 36. In 1890 and 1891, second rows were added in a few bad places. In these two years, the Railway Administration supplied the material required for screens free of cost and the Irrigated Service erected them. The Railway Administration recognised the good they were doing to the railway itself. Screens made up to the end of 1889 were 1½ metre high, composed of cotton stalks kept in position by upright timbers and horizontal laths. The railway supplied 'tarfa,' which is more enduring than cotton stalks and does not require timber supports. It is stuck into the ground at an angle and roughly plaited together, the completed screen being about 1 metre. It is needless to say it is much the cheaper of the two kinds.

Sand screens are of no permanent value. They are soon buried and others

have to be made either behind or on the top of the first row. This might go on for ever, unless other means are found for arresting the movement of sand. Nevertheless they did incalculable good from 1887 to 1889. An instance of this was seen in 1888, when screens erected but a few months were entirely buried. I calculated that 150,000 cubic metres of sand on a length of a few kilometres had been prevented from falling into the canal Owing to the good results of flooding the desert, the growth of herbs and grass, screens are no longer required, except in a few isolated places, where hillocks adjoin the railway and therefore never are surrounded by water.

I have already described what has been done towards flooding the western desert up to the end of 1887. The Nile flood of 1888 having been a very bad one, water could not be spared for these desert basins. Most of the small herbs withered and there was an increase in drift sand. In 1889, 1890 and 1891 a full supply has been given with most satisfactory results. Tall grass and several kinds of small herbs have increased in a wonderful manner. Where the depth of water is too great to allow of vegetation surviving, a thin deposit of mud has caused the surface to cake. The neighbourhood of kilometres 32 to 35, which gave most trouble by drift sand, is now a mass of green.

Regulation of water through the basin banks of Abu-Ghalib and Beni-Salama was rendered much easier by the construction of masonry regulators. The Rimal bank was cut through and water held up to the level of the Iswid basin on the Abu-Ghalib. The level of the Beni-Salama basin was also raised; in both cases resulting in a larger area being flooded. Nevertheless there are several hillocks on kilometres 12 to 17 which cannot be covered, but they do little harm since grass has grown on them. The canal mentioned as having been dug in 1887 has been deepened and widened, thus permitting water to enter the desert earlier in the flood season. Grass planted on its banks has prevented wind from blowing sand into the bed. In 1890, the Naza bank was made, which limits these desert basins on the north and prevents land beyond from being inundated. A drain on the south side of this bank connects the basins with the Khatatbah, in the bank of which—at kilometre 44, that is 3 kilometres from its head—an escape was built in 1888. With these regulators and escape it is possible to pass 1½ million cubic metres of water daily from the Iswid basin into the Khatatbah Canal, viâ the western desert.

A statement at the end of this Report gives details of expenditure.

The total sums spent have been as follows :—

Detail	Prior to 1888	1888 to 1892	Total
	£	£	£
Dredging, including removing stone dams	19,829	157,772	177,601
Spurs	14,238	8,548	22,786
Plantation	581	1,674	2,255
Sand screens	753	773	1,526
Flooding	3,389	7,691	11,080
Contingencies	451	586	1,037
Totals . . £	39,241	177,044	216,285

Of work done prior to 1888, all dredging and the greater part of spur making was rendered useless, the former failing because the latter were made of inferior material, cheap spurs having been found useless, as stated in this Report. After deducting useless work, the balance spent prior to 1888 was 9412*l.*, which was work which has lasted.

Neither the Khatatbah nor Atfah pumps have been used since the season of 1890, and the quantity of water provided for the Beherah Province has been increased from 58 to 80 cubic metres per second.

Pumping cost in 1888	£61,255
1889	59,999
1890	49,822

The money saving effected by the restoration of the Rayyah Behera may therefore be taken with reference to the expenditure of 1888, as in 1889 and 1890 the Royal Behera supplied 15 cubic metres per second and so reduced the quantity pumped.

In 1889 it was	£1,256
„ 1890 „	11,433
„ 1891 „	34,935

In the latter year the expenditure was 26,320*l.* which is the annual subsidy paid to the company whether water is taken or not. Total to the end of 1891, 47,624*l.*

In future years the saving will be 35,000*l.* less the cost of maintenance of Rayyah Behera, which should not exceed 10,000*l.* (this I think a high estimate). The actual annual saving will therefore be 25,000*l.*

The Rayyah Behera will require the most careful watching for some years. Wherever erosion of banks appears a spur must be erected. Grass must be renewed wherever necessary. Dredging must always be done over the bank, that is to say, that dredged stuff must be discharged outside the bank, and always on the right or east side from kilometres 9 to 41. Desert plantation must be continued until sand drift ceases entirely. Unless the flood is a very bad one, desert basins should be filled. They should never be drained, but allowed to dry up, thus prolonging the period of water supply. In years of good flood a continuous supply of water should be passed through the chain to increase the mud deposit. The western desert should not be sold or rented, at least not for many years hence.

The Rayyah Behera must not be used during high Nile before regulators have been built."

The following is taken from Mr. Foster's Report for 1892 :—

"Owing to the regulating gates at the Barrage having been carefully caulked, the two branches were practically dry.

Infiltration from the banks was insufficient to prevent salt water from finding its way up the Damietta branch, which it did as far as Shirbin, that is, 70 kilometres from the sea, and 175 kilometres from the Barrage.

The usual dam having been made across the Rosetta branch, 20 kilometres south of the town of Rosetta, the distance to which salt water travelled was limited.

The discharge of the river at Cairo was gauged on the 2nd July by measuring water entering all canals, when it was found to be 290 cubic metres per second, the Barrage gauge reading R.L. 13·32. As the water surface had fallen to R.L 13·22 (on 2nd June), this was not the minimum discharge.

Rotations had to be enforced everywhere, and with the greatest strictness.

The actual and relative periods of supply and non-supply vary greatly in different localities. Generally speaking cotton canals will do very well with ten days' alternate supply and closure. In Menufiyeh, however, the cotton did very well with seven days' supply and thirteen days' non-supply.

In its early stages rice should not be deprived of water for more than three or four days; to do so means, if not destruction of crop, at least partial loss of produce.

The quality of soil, however, has much to do with the power of rice to withstand drought.

The nearer a constant flow through the rice fields can be approached, the better the crop.

The following gives dates of commencing and suspending rotations :—

Province	Rotations Commenced	Rotations Stopped	Remarks
Qalubiyeh . . .	17th June	16th July	(*a*) Rotations were never enforced on Sharqiyeh Canal.
Sharqiyeh (*a*) . .	16th "	9th August	
Daqaliyeh . . .	17th "	30th July	
Menufiyeh . . .	28th May	6th August	(*b*) In rice District, rotations not commenced until 27th June."
Gharbiyeh . . .	28th " (*b*)	8th "	
Beherah . . .	1st June	18th "	

The following selection is from Major Hanbury Brown's Report for 1894 :—

"As, during the year 1894, the large pumping stations at Khatatbeh and Atfeh became the property of Government by an arrangement concluded with the Behera Irrigation Company, it will be convenient to record their history in this Report under the head of Summer Irrigation, to provide for which they were set up.

According to Linant, Alexandria in 1810 was a purely Arab town; it developed in Mehemet Ali's reign. Communication between Alexandria and Cairo was carried on, up to 1819, by sea from Alexandria to Rosetta or Damietta, or by land to Rosetta, and thence by river to Cairo.

At this time Alexandria obtained its water supply from cisterns filled by the winter rains or by flood water from the river arriving by way of the old canal of Alexandria and by percolation. This old canal of Alexandria had its mouth on the Rosetta branch of the Nile at Rahmaniyah, and on its way to Alexandria passed by Zawyet el Ghazal. Mehemet Ali replaced this canal by the Mahmudiyah with its Nile intake at Atfeh and its junction with the old canal at Zawyet el Ghazal. The Mahmudiyah was designed to be navigable, but long after its excavation transhipments had to take place at Atfeh, until in 1842 a lock was constructed there.

During flood and early winter the Mahmudiyah Canal derived its supply from the Khatatbeh Canal, which tails into it at 15 kilometres from the river at Atfeh, at which place also the flood waters were admitted to the canal. Later in the year, on the Khatatbeh Canal ceasing to flow into the Mahmudiyah, the supply was kept up for some time longer by means of water stored in an artificial reservoir of feeble capacity, known as the 'Khazzan,' and admitted to the canal by the Zargan regulator. This reservoir, which was filled during flood, covered about 10,000 acres on the south sides of the first 8 kilometres of the Mahmudiyah Canal, the left bank of which formed the retaining bank of the reservoir. The depth of water in the reservoir was not enough to provide a sufficiently prolonged supply, and thus the crops depending on it suffered and the town of Alexandria had to fall back on its cisterns, of which hundreds still exist, though no longer used. After the Atfeh pumps were set up the reservoir ceased to be maintained as such, and its bed was brought under cultivation.

As the Mahmudiyah supply under these conditions was unsatisfactory, Linant Bey in 1849 proposed the creation of a pumping station at Atfeh, which project was prepared by Mougel Bey and d'Arnaud Bey, and carried out by the latter. But, with this pumping station, Alexandria, as Linant records, had not enough water in 1869 and 1870, and moreover in spite of the deficiency, an engine was erected on the canal to supply Ramleh: whence he concluded that the pumping station at Atfeh must be enlarged.

The first pump set up at Atfeh consisted of two large beam engines of English make driving four small turbines, the discharge from which was probably not more than 5·5 cubic metres per second. Some years later the pumps were changed for others of modern type, the engines remaining as before. About 1870 this pumping station was enlarged and made capable of lifting 10 cubic metres per second, but the supply was not constant, until the Behera Irrigation Company in 1881 took the contract for working the pumps.

During the period from 1847 to 1870 the Barrage had been built, had failed and been condemned as a useless structure, and it was therefore determined to supply the Delta with summer water by means of enormous pumping stations. The Beherah Canal also had failed, and the influential landowners of Beherah having made their voices heard in the public offices in Cairo, it was decided to apply the system first to Beherah, by erecting a new pumping station at Khatatbeh and enlarging the existing one at Atfeh. The contract for carrying this out was given to the Beherah Irrigation Company in May 1880. This company undertook to make the new and to enlarge the existing pumping station, and to deliver 17 cubic metres per second from each station. In January 1883 the quantities to be delivered were increased to 29 cubic metres per second at Khatatbeh and 23 at Atfeh. The lift at Khatatbeh was about 2·65 metres as a maximum and 2·00 metres as a mean; and at Atfeh 2 metres as a maximum and 1·20 as a mean.

Mr. Foster gives the following description of these pumping stations:—

'From February 1881, the Afteh pumps were to give 17 cubic metres per second. However the Afteh pumps were worked to the utmost of their capacity, but the 17 cubic metres were not produced. The company then decided to employ the Sagobien wheel. When I first saw the Afteh station in May 1894, four of these wheels were working on the two beam engines and doing very good work, and delivering almost as much water as required. In January 1883, Government made

another convention by which the company undertook to supply 23 cubic metres per second. By the season of 1886 four more wheels on the same design were added, worked by two inverted marine engines. The whole eight wheels have lifted as much as 35 cubic metres per second. They are the most efficient water lift for low lifts in existence. By carefully made experiments they showed 95 per cent. effective duty. The Atfeh pumps never gave any trouble after 1886.

'The increase in the quantity of water supplied to the Mahmudiyah by the Atfeh pumps has been approximately as follows :—

	cubic metres per second
'1858 to (1868?)	6
1869 (?) to 1881	10
1882 to 1885	17
1886 until pumps suppressed	23 to 35

'The cost of lifting water before 1881 is not known; probably it was enormous. Since that date, however, all has been done by contract at the following rates :—

'By the contract of 1880, 24*l.* per million metres cube. This was increased by the convention of 1883 to 26*l.*, until 1885, and from 1886 to 28*l.* per million metres cube.

'Although the Atfeh pumps worked for a few days in 1892, 1893 and 1894 on the rising flood, they may be considered to have ceased to function when they were stopped in August 1890.

'At Khatatbeh the Behera Irrigation Company made the unfortunate mistake of trying to turn ten Archimedean screws on one single shaft. To give the full supply required, ten screws had to be used. Three inverted marine engines worked on the one shaft, one or more working according to the number of screws in motion. This experiment proved a great failure. In 1881, when these pumps were supposed to be delivering 17 cubic metres per second, the foundations of the pump house were not laid. Very great difficulties were encountered, and when at last the Archimedean screws were got to work they failed hopelessly.

'The convention of 1881 above mentioned gave an extension of time, but it was of no use: the system was bad and nothing would make it good. By the convention of 1883 the company undertook to remodel the Khatatbeh station, and to guarantee 29 cubic metres per second.

'The firm of Farcot, of Paris, was employed to supply the new pumps, and they sent out exceedingly fine machinery. Three Archimedean screws were retained, and the remaining seven removed and replaced by five direct-acting centrifugal pumps, each driven by a separate Corliss engine. Nor did the new installation work smoothly at first. Lubrication of such immense pumps gave trouble, but by the end of the season of 1885 all difficulties were overcome, and the five pumps would lift 29 cubic metres per second. The maximum volume of water lifted by all the pumps together, including the three Archimedean screws, was under 35 cubic metres per second. The pumps continued to work without hitch or hindrance until finally stopped on the 10th April, 1890, since which they have never been used.'

The actual quantities pumped and paid for at the two stations are given on page 205.

As has been stated elsewhere, the causes which led to these pumps being no longer required after 1890, were the restoration of the Barrage and of the Rayyah Behera Canal.

—	Khatatbeh		Atfeh		Subsidy	Total Amount
	Cubic metres	Amount	Cubic metres	Amount		
		£		£	£	£
1881	All records burnt in 1882			4,795	13,200	17,995
1882				4,305	12,000	16,305
1883	89,482,776	3,039	246,614,315	6,372	17,277	26,688
1884	110,896,840	4,325	209,598,170	5,573	17,277	27,175
1885	58,401,144	2,327	218,827,770	5,871	21,296	29,494
1886	335,607,609	14,096	379,206,529	10,867	26,320	51,283
1887	389,341,635	16,381	384,750,624	11,185	26,320	53,886
1888	480,915,639	20,583	579,026,203	19,053	26,320	65,956
1889	461,717,639	19,639	420,222,301	12,020	26,320	57,979
1890	155,801,377	6,548	442,585,087	13,663	26,320	46,531
1891	..	..	..	..	26,320	26,320
1892	..	..	28,000,000	1,000	26,320	27,320
1893	..	..	51,386,818	1,845	26,320	28,165
1894	..	..	6,299,277	290	8,773	9,063"

Since 1893 the summer supply of the Nile has been abundant and the irrigation exceedingly liberal. Very many of the main canals and a still larger number of the minor canals have been dammed across at some part of their course and their lower reaches converted into drains, thus depriving the canals of their power of escaping freely all excess water which may come down in flood and winter. Every effort is being made to minimise these evils, but in my opinion no substantial relief will be found until both escapes and drains are amply provided in the manner described in Chapter VIII.

The final selection is from Major Brown's Report for 1896:—

"The rainfall during the winter of 1895 to 1896 was above the average, so that there was no difficulty in providing for all the irrigation necessary during the period when the canals were closed for carrying out the winter clearances. But, on the other hand, the execution of these clearances was rendered difficult by the abundant rainfall, which delayed the drying up of the canals after they were closed for clearance and made the removal of the slushy silt laborious. The drains were further overtaxed and were unable to carry off the excess water, which reached them, as quickly as was desirable. More might be done to meet such conditions by promptly reducing the canal discharges flowing to those districts where rain may fall from time to time, and orders have been sent out to inspectors of irrigation to pay attention to this necessity in future winters.

The summer levels of the Nile were again favourable ones, and consequently the difficulties of distribution were not great. Profiting, however, by the experience of the preceding year, rotations were commenced on the 20th June in anticipation of the increased demand for water, which always comes early in July, when the lands, not under cotton, are flooded to prepare them for the sowing of the maize crop, an operation which every one seems anxious to carry out at one and the same time. Consequently, no matter how plentiful the supply, every one cannot be satisfied, as

the canals are incapable, even with full supply, of carrying enough to irrigate, or rather inundate the large areas which the cultivators are anxious to get sown with maize, as quickly as their impatience demands. Therefore we must expect that, between the 10th July and the end of August, there will be annually a period of complaints and urgent demands for water, more or less pressing according as the Nile flood is late or early in commencing to make itself felt in Lower Egypt. During this period of absorbing interest in the sowing of maize, there is danger lest the cotton and rice crops at the tails of canals, which have been successfully irrigated up to the end of June, should be sacrificed to the eagerness for an early sowing of the maize crop; and it is to guard against this danger that rotations are put on at the end of June and continued sometimes to the middle of August, while, in addition, the level above the Barrage is gradually raised by regulation during July. In the summer of 1896 rotations were applied to the Lower Egypt canals between the following dates:—

First Circle, Dakahlyah Province and part of Sharkiyah	20th June to 29th July
Second Circle, Menufiyah and Gharbiyah .	20th June to 12th Aug.
Third Circle, Beherah	20th June to 15th Aug.

It has been ascertained that the blessing of an improved water supply, which has resulted from the Barrage having been made to do its duty, has been attended in some localities with the evils due to infiltration and want of drains. The remedy, as pointed out in last year's Report, is to remove the want of drains by digging them, and to provide the means of washing out the salt, brought to the surface by infiltration, in the shape of a liberal supply of water, by which the salt would be carried away in solution along the drains, or be forced down below the surface of the soil to a depth at which it would be harmless. The liberal water supply is not to be obtained except by the construction of a storage reservoir at Aswan or elsewhere; the drains cannot be dug without more abundant funds than the ordinary Irrigation Budget allotments provide.

Hence it has become necessary, while hope is being deferred * and drains are still incomplete, to consider if the evils of infiltration can be cured, or at any rate be prevented from spreading, by any means that are at present possible to us. It has, therefore, been proposed, with this object, to make the drains more efficient as drains by lessening the excessive amounts of water which are passed down the canals for purposes of irrigation or inundation during winter, spring and flood; and to effect this reduction by periodically lowering the water level in the canals, so that, instead of producing infiltration and helping to fill the drains to overflowing, their channels shall themselves act as drains to reduce infiltration and carry off surplus water. During the period of low water level of 'spring rotations,' the main supply will be reduced and all regulators be kept fully open, so that the water level may be kept low everywhere. Water wheels and pumps will not be stopped working, and any one may take water if he can get it, provided he does not attempt to raise the natural water level in the canal. So that the ordinary objection, that the application of rotations gives opportunities to dishonesty for feathering its nest, will not apply to winter or spring rotations conducted on the above principles.

* Written before it was known that, in 1897, 250,000*l.* were to be allotted for drainage.

The adoption of this system was decided on too late in the spring of 1896 to do more than make a small beginning.

Flood rotations consist in considerably reducing the flood supply at fixed intervals. The necessity of this periodical reduction arises from the fact that many of the main canals have to be run at discharges greater than those required by the amount of irrigation to be done, in order to produce water-surface levels sufficiently high to irrigate without lift the adjacent lands. Consequently there is an excess amount of water turned on to the land, which does no good, but goes directly into the drains. They are thus prevented from doing the beneficial work that they would otherwise do in carrying off the normal amount of drainage, which would be due to the discharge restricted to what could be *usefully* employed in irrigating crops. To reduce the ill effects thus resulting from the necessity of producing high levels by a discharge in excess of requirements, flood rotations were introduced in 1896. They gave rise to no complaints, and must have effected a considerable relief to the drains and so have contributed to better drainage. What was done in this direction in 1896 was merely tentative, but the results were sufficiently encouraging to induce us to continue the system and to apply it in a more thorough manner in the future.

To distribute the water, so that all requirements of irrigation and drainage shall be met, is no simple matter. During flood it is desirable to be liberal with the red-water supply and to deliver it abundantly to all parts of the country. At the same time infiltration must be kept down and the drains must not be overtaxed. Free-flow irrigation is a necessity for washing salt out of bad lands and for keeping down the cost of raising crops on lands which would give no profit, were lift irrigation only possible in their case; but free flow means high levels and an increase in the drainage water to be run off: continued high levels also waterlog the soil and render it sour. Rotation produces high and low levels alternately, keeps the water in the soil from stagnating, gives free flow during one period, and provides for helping the drains the next, and is undoubtedly the most healthy system to adopt for water distribution in a country such as Lower Egypt is. It is proposed, therefore, to apply it according to the following programme, which is a provisional one, subject to such modifications as experience may show to be desirable:—

General lowering of canals for clearances	20th December to 31st January.
Winter supply without rotations	February, March and April
Spring rotations	1st May to 20th June
Summer rotations	21st June to 20th August
Full flood supply everywhere	21st August to 20th September
Flood rotations	21st September to 30th Nov.
Maximum supply required, without rotations	1st December to 20th December.

It may be found possible to commence spring rotations earlier than the 1st May. Summer rotations will sometimes cease earlier than the 20th August, and, if so, the flood full supply for a month will begin and end earlier, and flood rotation will begin earlier, but will continue to the end of November. No rotations are at present proposed during February, March and April, as, after the period of general lowering for clearances, all the winter crops require irrigating, and, by the time this is done, cotton sowing commences and extends into April."

CHAPTER VII.

EGYPT BY PROVINCES.

Assuân, classes of land, proprietors, population, rents, taxes, nitrates in the deserts, crops, neglect of navigation—*Kena*, classes of land, proprietors, population, rents, taxes, nitrates in the deserts, sugar factories, crops, faults in basin irrigation—Samhûd basin—*Sohag*, classes of land, proprietors, population, rents, taxes, land sold up after years of drought, Sohagia Canal, superb basin irrigation, independent peasantry, sugar and butter factories, crops—*Assiout*, classes of land, &c., taxes, good and bad basin irrigation, Ibrahimia Canal, sugar factories, excellent land near Roda—*Minia*, classes of land, &c., taxes, perennially irrigated tracts, deterioration from over-saturation, proposed remedies, sugar factories, cotton, inferior basin irrigation and travelling sand in the deserts—*Beni-Suef*, classes of land, &c., taxes, excellent perennially irrigated land, poor basin irrigation and remedies, good and bad perennial irrigation contrasted, crops, sugar factories—*Geeza*, classes of land, &c., taxes, crops, good well irrigation, sugar factory, basin irrigation indifferent—*Fayûm*, classes of land, &c., taxes, crops, proposals for the irrigation and the Garak—*Behêra*, classes of land, &c., crops, the lakes, Katatbeh Canal remodelling, Canopic branch, great lack of escapes, irrigation by pumps compared with that from Barrages—*Menoufia*, classes of land, &c., crops, excellent irrigation and land—*Garbia*, classes of land, &c., crops, necessity for additional water in summer, proposed Samanûd weir, drainage and escapes—*Kalyubia*, classes of land, &c., crops, excellent irrigation and land—*Sharkia*, classes of land, &c., crops, Rayah Tewfiki, excessive flush irrigation, remedies proposed—*Dakalia*, classes of land, &c., crops, Bahr Sogair and Bobya compared, Tanah-Gabbada drainage, Colonel Ross's saying about red water, basin and perennial irrigation compared.

THE following notes were written in April 1897, immediately after I had spent two years examining the whole of the agricultural land of Egypt.

Assuân Province.—The Assuân Province stretches from Wady Halfa to Kelh el Gebel.

Description of Land	Extent in Acres		
	Left Bank of the Nile	Right Bank of the Nile	Total
Basins	15,800	4,000	19,800
Nile berms . . .	24,400	29,300	53,700
Total . . .	40,200	33,300	73,500

The 73,500, or to speak exactly, the 73,538 acres of this province are thus subdivided among the different classes of proprietors:—

	acres
Resident Egyptians	65,000
Non-resident Egyptians	3,493
Foreigners	48
Wakf, or Moslem religious trust	581
Daira Sania (State) Administration	4,416
	73,538

The population is 240,382, or 320 per 100 acres.

The mean renting value of the land is 1·60*l.* per acre, with the rents varying from 3·00*l.* to ·50*l.* per acre. The mean tax is ·43*l.* per acre, or 28 per cent. of the rent.

Between Halfa and Assuân there lie 21,000 acres on a length of 345 kilometres, giving a mean width on either bank of the Nile of 130 metres of cultivation land. North of Assuân there are 52,500 acres on a length of 120 kilometres, giving a mean width on either bank of 930 metres. It is owing to the great proportion of the land lying within reach of the river that the land is irrigated to so great an extent throughout the year. The greater part of the dense population spend their lives lifting water from the Nile on to their fields. Cattle are costly to keep and consequently everything is done by manual labour. The resident population south of Assuân receive considerable aid from their relatives in Cairo, Alexandria and the cities of the Delta, where they have monopolised the occupation of cooks and house servants of all classes.

The hills provide nitrates in plenty, and the lands are generally well cultivated, though the yield is poor as the water has to be lifted to so great a height. Between Halfa and Assuân there are 800 acres of land at Deberra which are irrigated as basins in an ordinary flood, and a small tract south of Korosko which is irrigated flush in a high flood. With these exceptions the area south of Assuân is irrigated lift throughout the year. The lift varies from 8 to 10 metres in summer and 1 to 3 metres in flood. Between Assuân and Kelh are a few insignificant basins on the right bank, and one or two good basins on the Ramâdi Canal near Edfu. The greater part of the land is irrigated lift except in good floods.

The principal crops are sorghum, pulse (âds), barley, vetches (gilbân), beans (ashrangêk), lettuce and castor oil. Beans and wheat are grown on the rich basin lands, while the foreshores are covered with melons and cucumber. The date palm is being extensively cultivated, especially at Ibrim and the surrounding villages.

The most valuable lands in this province and in Kena are the recently formed and low-lying berms of the Nile, while the least valuable are the ancient and high-lying berms which have been heavily manured with nitrates for centuries and never washed by the Nile flood.

It is most unfortunate that no attempts have been made to repair and renew the ancient training works of the Egyptians and Romans. Costly railways are being constructed along the narrow strips of cultivated land in a country without fuel and without coal, while the magnificent river, which needs only a few intelligently planned new training works and the repairs and restoration of those of the ancients to make it perfectly navigable throughout the year to boats drawing 1 metre of water in extreme low supply, is neglected. And yet everything marks out the Nile for navigation: all the important towns are on its banks, and so is all the life and commerce; the current is always from south to north and the breeze nearly always from north to south; the supply is well maintained throughout the year, and the velocity is never severe.

Kena Province.

Description of Land	Extent in Acres		
	Left Bank of the Nile	Right Bank of the Nile	Total
Basins	172,700	113,900	286,600
Nile berms . . .	18,800	37,500	56,300
Total . . .	191,500	151,400	342,900

Of the 172,700 acres of basins on the left bank 37,000 are enclosed for sugar-cane and ordinary perennial crops, and of the 113,900 on the right bank 5000 are so enclosed.

The 342,900, or to speak exactly, the 342,936 acres are thus subdivided among the different classes of proprietors :—

	acres
Resident Egyptians	251,747
Non-resident Egyptians	27,334
Foreigners	12,284
Wakf (Moslem religious trusts)	6,316
Daira Sania (State) Administration	45,255
Total	342,936

This is another province where by far the greater part of the land is in the hands of residents. The population is 711,457, or 206 per 100 acres.

The mean rental of the province is 2·60*l.* per acre, while the rents vary from 4·00*l.* to 1·50*l.* per acre. The mean tax is ·66*l.* per acre, or 26 per cent. of the rent.

As the left bank of the Nile has 191,500 acres on a length of 245 kilometres, and the right bank 151,400 acres on a length of 225 kilometres, the mean width of the cultivated land on the left bank is 3280 metres and on the right 2830 metres. It is an interesting fact that the only reach of the Nile where the areas on the right and left banks are at all like each other in extent, is also the only reach where the Nile is often flowing east and west and not continually north and south. Where the Nile flows north and south, nearly the whole of the cultivated land is on the left bank.

The hills south of Gebelain provide nitrate in plenty, and north of it in insignificant quantities. There are also a few ancient mounds, such as Mataana, Edfu and Dendera, which provide valuable manures. Wherever spring water is abundant, as it is in the neighbourhood of Basilia, Esna, Luxor and Farshût, and generally along the edges of the desert, there are extensive areas of summer sorghum and sugar-cane, and the winter crops are both manured and irrigated. The area under flood sorghum is also very extensive in this province. The smaller the basin and the shallower the water in flood, the more extensive is the sorghum crop as a rule. Double cropping is becoming a necessity in these southern provinces, owing to the great increase of population and the presence of so many mouths to feed.

The Daira Sania Administration has three powerful pumping stations and sugar factories at Mataana, Armant and Dabaya; the horse-power of the engines, and the capacity of the factories is given below:—

Name of Factory	H.P. of Pumping Engines	Water discharged, in cubic metres per minute	Area Capable of Irrigation	Out-turn of Sugar in tons * (capacity)
Mataana . . .	150	38	1500	5000
Armant . . .	250	62	2500	6000
Dabaya . . .	150	38	1500	5000
Total . . .	550	138	5500	16000

* 1 ton = 23 kantars.

The out-turn of the three factories in tons in 1896–97 was 3200, 4600 and 4100; and in 1897–98 was 2800, 2800 and 2800 respectively.

The Société Générale des Sucreries de la Haute Egypte has a pumping engine and factory at Naga Hamâdi. The horse-power of the engine is 500, the water discharged per minute is 125, the area capable of irrigation is 5000 acres, and the capacity of sugar out-turn in tons is 24,000. The actual quantity of sugar manufactured in 1896–97 was 3000 tons, and in 1897–98 was 4700 tons.

In addition to the above, the province of Kena in the neighbourhood of Naga Hamâdi has numerous mills and molasses factories scattered among the villages belonging to the fellaheen themselves. The sugar-cane is grown in the basin enclosures, and irrigated from wells in the fields worked by Persian weeels.

The principal crops are sorghum, wheat, beans, pulse (âds), vetches (gilban) south of Kena and clover north of Kena, barley, sugar-cane, melons and cucumbers.

The basins are generally well irrigated, and supplied with abundance of water in the northern parts of the province. The southern basins are well irrigated but not very plentifully, as the slope of the country does not permit of it. The Samhûd basin in the extreme north of the province is one of the best irrigated and richest basins in Egypt, while the subsoil water is plentiful.

At various points in this province, especially at Basilia, Esna, Mahamîd, Akalta and Shawria, attempts should be made to allow the high-level water of high floods to cross the main feeder canals and replenish the basins with rich deposit. Colonel Ross's works have improved the supply in years of ordinary and low flood, but have deprived the basins of rich supplies in very high floods when the Nile could easily do its irrigation without the long feeder canals of to-day. Either by powerful syphons or by inlet and outlet works such provision should be made, or these lands will deteriorate for want of their periodical renovation which they used to receive in the past, when the canal heads were twice as numerous as they are to-day.

The fact that Samhûd basin does not easily command the Nile at Abu Shûsha is another weak point in the new system, and will always need careful consideration if the Nile happens to be high and to keep high at the time of discharge.

P 2

Sohag Province (formerly Girga).

Description of Land	Extent in Acres		
	Left Bank of the Nile	Right Bank of the Nile	Total
Basins	227,900	47,600	275,500
Nile berms . . .	34,000	15,500	49,500
Total . . .	261,900	63,100	325,000

The 325,000 acres, or to speak more exactly, the 324,958 acres of this province are thus subdivided among the different classes of proprietors :—

	acres
Resident Egyptians	284,517
Non-resident Egyptians	35,775
Foreigners	4,154
Wakf (or Moslem religious trusts)	512
Total	324,958

The population is 688,011, or 211 per 100 acres. The mean renting value per acre is 2·91*l.*, with 1·50*l.* as a minimum and 4·00*l.* as a maximum. The mean tax is ·92*l.* per acre, or 32 per cent. of the rentals.

Great part of the land in this province which no longer belongs to the fellaheen was sold up after years of drought. Extensive tracts of land left unirrigated were reported as irrigated by the civil authorities. The canal officials supported the statements of the civil authorities, and the Cairo Government ordered the sale of the lands, as the fellaheen could not pay the taxes. The lands were ordinarily bought up by the officials and their friends at nominal prices. It is in places where the fellaheen have been thus deprived of their lands that brigandage is most often rife. It was the sight of such places and the knowledge of such facts which urged on Colonel Ross to thoroughly complete the works for drought prevention which he had undertaken. His kindly and generous heart warmed to the task, and to-day there is no name more respected in Upper Egypt than his, and no work more satisfactory.

The left bank of the Nile has 261,900 acres on a length of 120 kilometres, and on the same length the right bank has 63,100 acres. The mean width of cultivated land on the left bank is 9020 metres, and on the right 2200 metres.

The best basin canal in Egypt, the Sohagia, traverses the northern half of the province. It has a bed width of 70 metres, and a depth of 5 metres of water in an ordinary flood. The ordinary discharge is 400 cubic metres per second, and the maximum discharge 520 cubic metres per second.

The large area under basin irrigation on the left or main bank of the Nile as compared to the other kinds of irrigation is a new feature as we descend the Nile. Girga, indeed, with southern Assiout is the centre of basin irrigation in Egypt. Here

we see basin irrigation at its best. The land is rich, the crops luxuriant, the people well off and independent, and the subsoil water well utilised. We nowhere again see such general wealth and prosperity until we reach the deltaic province of Menoufieh. In the centre of one of the richest tracts are the ruins of Abydos, and near to the reputed site of This or Thinis, the first capital of Egypt. The peasantry of this province are the most independent and truthful which are to be found in Egypt, while the village headmen are the most reliable and outspoken. This was my personal experience after many years' residence among the villages, and I learnt subsequently that the Khedive's bodyguard is recruited from this province alone as the peasantry are considered the most reliable in the country. And indeed an agricultural community, whose lands are never liable to drought, whose flood waters no engineer can cut off, and whose plentiful subsoil water at a convenient level is their own property with which no government official or powerful neighbour can interfere, enjoy a freedom and independence which is very rare in Egypt.

This province is the most rainless in Egypt, as it gets its rain neither from the north in winter, nor from the south in autumn. The hills provide no nitrates to speak of, but the cattle are very numerous, and in the south there are many ancient ruins which supply manure. The Nile deposit in the basins is generally very good. Here Colonel Ross spent great part of the 800,000*l.* loan, and improved every basin he touched.

The subsoil springs are generally plentiful, and wells numerous.

A pumping station and sugar factory has recently been erected near Balyana by the Egyptian Sugar and Land Company. The indicated horse-power of the engines for pumping is 400; the discharge per minute is 100 cubic metres; the area capable of irrigation is 4000 acres; and the capacity of sugar out-turn in tons is 7000.

The principal crops are wheat, beans, clover, millets, barley, onions and sugar-cane.

There are butter factories at Menshia and Tahta, and an ice factory at Tahta.

Assiout.

Description of Land	Extent in Acres		
	Left Bank of the Nile	Right Bank of the Nile	Total
Basins	291,000	72,800	363,800
Nile berms . . .	17,700	7,200	24,900
Perennial irrigation .	32,800	..	32,800
Total . . .	341,500	80,000	421,500

The 421,500, or to speak more exactly, the 421,473 acres in this province, are thus subdivided among the different classes of proprietors :—

	acres
Resident Egyptians	324,171
Non-resident Egyptians	40,233
Foreigners	14,875
Wakf	840
Daira Sania Administration	34,871
State Domains Administration	6,483
Total	421,473

The population is 782,720, or 185 per acre.

The mean renting value is 3·15*l.* per acre. For the perennially irrigated tracts the rents vary from 3*l.* to 6*l.* per acre, and for the flood tracts from 2*l.* to 4*l.* The mean of the perennially irrigated tracts is 4·70*l.* per acre, and of the basin tracts 3·00*l.* per acre.

The taxation amounts on the average to 1·05*l.* per acre, or 34 per cent. of the renting value.

The left bank of the Nile has 341,500 acres on a length of 165 kilometres, and the right bank 80,000 acres on a length of 175 kilometres. The mean width of cultivated land on the left bank is 8700 metres, and on the right bank 1900 metres.

The basins on the Sohagia Canal from Assiout to Delga have been long deprived of their full share of water from that magnificent canal, but they are being now re-supplied with water from the same source. A syphon is badly needed under the Ibrahimia Canal at its head to connect the basins on its right bank with the Sohagia, from which they were cut off when the Ibrahimia Canal was constructed. The basins north of Assiout are generally poor, but if liberally supplied with water they ought to regain their ancient fertility. Manfalut, the centre of this tract, was once one of the most prosperous agricultural towns in Egypt, and the centre of sugar-cane cultivation. The basins on the right bank of the Nile are well irrigated, and received considerable attention from Colonel Ross. On the left bank of the Nile the Abutig and Delgawi escapes were built out of the loan for drought prevention, but the drought prevention works may be said to have ceased at the town of Assiout. The whole basin system of irrigation from Assiout to Cairo needs to be thoroughly taken up, and a special grant for this purpose would repay itself in a few years.

The Ibrahimia Canal has its head in this province. It traverses the northern half of the province with its water surface in soil through the winter and summer. North of Deirut it is at a very convenient level for lift irrigation, aided by the Deirutia and Sahilia canals. This tract has the further advantage of having situated in its centre the extensive mounds of Ashmunên, which supply unlimited manure. The lands are not generally over irrigated, and some of the best of the Daira property is in this province. The only lands which are decidedly salted and deteriorating are those north of Ashmunên, where high-level canals traverse a very sandy clay soil and have succeeded in saturating and partially ruining it.

The principal crops are wheat, beans, clover, sorghum, sugar-cane, cotton and barley.

There are two sugar factories in this province: one, the property of the Daira Sania, at Roda; and the other at Beni Korra, the property of Wisa bey, a wealthy landed proprietor.

The Roda factory has a capacity of out-turning 10,000 tons of sugar, and in 1896–97 turned out 9800 tons, and 7600 tons in 1897–98. The Beni Korra factory has a capacity of 5000 tons, and in 1896–97 turned out 1900 tons, and 1000 tons in 1897–98.

Minia Province.

Description of Land	Extent in Acres		
	Left Bank of the Nile	Right Bank of the Nile	Total
Basins	193,400	14,600	208,000
Nile berms	18,100	14,900	33,000
Perennial irrigation	166,400	..	166,400
Total	377,900	29,500	407,400

The 407,400, or to be more exact, the 407,485 acres in this province, are thus subdivided among the different classes of proprietors:—

	acres
Resident Egyptians	158,669
Non-resident Egyptians	95,852
Foreigners	16,613
Wakf	2,651
Daira Sania Administration	133,700
Total	407,485

The small proportion of land in the hands of resident Egyptians is very noticeable. The fellaheen of this province are generally very poor. They have scarcely any of the good lands in their possession.

The population is 548,632, or 134 per 100 acres. This is very low compared with a fellaheen province like Sohag with 211.

The mean renting value is 2·9*l.* per acre. For the perennially irrigated tracts the rents vary from 1*l.* per acre to 6·0*l.* per acre, and for the basin tracts from ·50*l.* per acre to 3·50*l.* per acre. The mean rent of the perennially irrigated tracts is 3·80*l.* per acre, and for the basin tracts 2·40*l.* It will be seen how low both these rates are as compared with those of Assiout.

The mean tax is ·75*l.* per acre, or 28 per cent. of the rents. There are very great inequalities in the taxes of this province, lands paying 50 per cent. of their rents lying side by side with lands paying 10 per cent.

The left bank of the Nile has 377,900 acres on a length of 100 kilometres, and the right bank has 29·500 acres on a length of 110 kilometres. The mean width of the cultivated land on the left bank is 15,900 metres and on the right bank 1,130 metres.

In the chapters on basin and perennial irrigations and on drainage the general features of this province have been already described. It remains to describe the

details. The perennially irrigated tracts in the southern half of the province have a general width of 3 kilometres, and in the northern of 8 kilometres. Where the width is narrow one main canal and one drainage cut running north and south are sufficient, but in the broad tract there should certainly be two if not three drainage cuts running north and south. The present single drainage cut is totally inadequate. These drainage cuts should not be only for drainage water but also for escape water from the canals and watercourses. Water should always be flowing. It is the dammed-up stagnant water at a high level in the canals and watercourses which does so much harm. While the canals and watercourses are being used for irrigation, the flow is healthy, but when irrigation is over, the water impounded in the canals and watercourses is not cut off at their heads but kept trickling down, and all these channels remain full of water at a high level in season and out of season. If the drainage cuts or escapes spoken of above were made and kept clean, and a system of weekly rotations adopted for the canals, by which they ran one week and were closed the next, there is little doubt that perennial irrigation would not be accompanied with the deterioration we see in this province, especially in the western half of the broad tract. The drains should, moreover, be provided with pumps to lift water into the tail escapes when the Nile and the basins in flood do not permit of free flow, unless the levels allow of drainage on the methods adopted in the valley of the Po, and explained in the chapter on drainage. The lands which were originally poor and have been thrown out of cultivation by perennial irrigation should be put under basin irrigation again and thoroughly renewed before they are provided with perennial irrigation for a second time. Mr. Wilson would like to see all lands which have deteriorated from over-cropping or over-irrigation put under basin irrigation every fourth year by rotation. Any definite system thoroughly taken up and carried out would be better than the plan of allowing great areas of good land to deteriorate year by year without an effort being made to save them from ruin. More blame possibly attaches to the proprietors than to the Government, but the Government is equally interested with the proprietors and could do much if it was so inclined.

In this province, the Daira Sania has four sugar factories, at Abu Girgas, Minia, Matai and Maghagha. They have capacities of out-turning sugar of 10,000, 14,000, 10,000 and 14,000 tons respectively. The out-turns of 1896–97 were 9000, 12,200, 7800 and 9600 tons respectively, and in 1897–98, they were 6100, 9400, 5500 and 8900 tons respectively.

On the left bank of the Nile, north of Minia, Sultan Pasha's family has a factory capable of turning out 3000 tons of sugar. In 1896–97 the out-turn was 2600 tons, and in 1897–98 it was 1800 tons.

On the right bank of the Nile at Shêkh Fadl, the Messrs. Suares have pumping stations and a factory. The pumping engines have a horse-power of 600, the discharge per minute is 150 cubic metres, the area capable of being irrigated is 6000 acres, while the capacity of sugar out-turn is 18,000 tons. The out-turn in 1896–97 was 8300 tons, and in 1897–98 it was 10,400 tons.

In many localities in this province the area under cotton is increasing, while that under sugar-cane is diminishing. Since sugar-cane is a more paying crop than cotton on good land, this is a sure indication of the fact that the land is generally deteriorating and becoming salted. The fall from sugar-cane to cotton in Upper Egypt corresponds to the fall from cotton and Indian corn in

rotation, to cotton and rice in rotation, which goes on in deteriorating land in the Delta.

The basins on the right bank of the Yusufi Canal are indifferently irrigated, and need far more red water than they receive. To be brought up to first-class level and rendered fit for the introduction of perennial irrigation they should have their red water supply doubled. No project in Egypt would pay better than the remodelling on Colonel Ross's lines of the basin irrigation of these lands, coupled with the basin irrigation on the miserably poor lands on the left of the Yusufi Canal. A regulator on the Yusufi Canal opposite Minia, and another at Behnessa, with a new feeder as large as the present Yusufi itself, from the Nile north of Minia would double and treble the value of the land, and in the course of twenty or thirty years render it capable of being perennially irrigated without subjecting it to the deterioration which the inferior Ibrahimia tracts have undergone. At the same time the flying sand hills on the west of this province, especially near Balansura, should be planted with grasses and tamarisks, and fixed somewhat after the manner of the work done near Wardan by Mr. Foster. It is generally accepted by all that the basin irrigation west of the Yusufi Canal, inferior and poor as it is, has been the cause of saving the left bank of the Nile from inundation by sand. If these lands could be covered by a great depth of red muddy water for some forty or fifty days every year, instead of as at present with clear white water for some four or five days, the sand which now invades the Yusufi Canal at Balansura would be stopped. This sand at present pours into the Yusufi Canal under the action of the north-west winds, and is swept in flood on the whole of the lands of the Minia Province irrigated by this canal, doing great harm wherever it goes. By plentiful basin irrigation and intelligently placed plantations all this evil might be stopped. The local people say that this moving sand was not nearly so active and virulent in the past, but that ever since Mehemet Ali settled the refugee Algerian Arabs along the western deserts, their camels and goats have eaten down the desert plants and shrubs, and the sand has begun to live. This question to-day is a really serious one.

The principal crops are sugar-cane, cotton, clover, sorghum, wheat, beans, barley and onions. The onions are principally grown on the lands annually covered by the Nile in flood.

Beni-Suef Province.

Description of Land	Extent in Acres		
	Left Bank of the Nile	Right Bank of the Nile	Total
Basins	174,500	1,200	175,700
Nile berms . . .	6,100	2,800	8,900
Perennial irrigation .	52,800	..	52,800
Total . . .	233,400	4,000	237,400

The 237,400, or to speak more exactly, 237,374 acres in this province are thus subdivided among the different classes of proprietors:—

	acres
Resident Egyptians	117,037
Non-resident Egyptians	102,652
Foreigners	1,930
Wakf	886
Daira Sania Administration	13,027
State Domains Administration	1,842
Total	237,374

The population is 314,454, or 131 per 100 acres.

The mean renting value is 3·05*l.* per acre per annum. For the perennially irrigated tracts the rents vary from 7*l.* to 3*l.* per acre, and for the basin lands from 4*l.* to 1*l.* per acre. The mean rental of the perennially irrigated lands is 4·50*l.* per acre, and of the basin lands 2·64*l.* per acre. The mean tax is ·93*l.* per acre, or 30 per cent. of the rentals.

The left bank of the Nile has 233,438 acres on a length of 70 kilometres, and the right 3936 acres on a length of 50 kilometres. The mean width of the cultivated land on left bank is 14,000 metres, and on the right bank 340 metres. Opposite Beni-Suef the Nile valley has its greatest width of 20 kilometres.

In this province, for the first time, we see a considerable area of perennially irrigated land in the hands of resident proprietors, and as this land is moreover near the Nile and of good quality in itself, the wealth and well-being of the population is very marked. No town in Egypt has made greater progress during the last 15 years than the town of Beni-Suef. The perennially irrigated land occupies a narrow strip up to Beni-Suef and then spreads out over the rich land to the north-west of the town.

The basins of this province, with the exception of the northern halves of Kushêsha and Rikka are very poorly irrigated. The same remarks apply to them as to the basins of Minia Province. If we compare the Sohagia system with the Yusufi system we find that the former receives 170 cubic metres per acre per day and the latter 90. But that is not all. Not only has the Yusûfi system a quite insufficient supply, but what there is cannot be utilised owing to the want of regulators, and nearly the whole of it finds its way into the northern half of the Koshesha basin and irrigates a tract which could be better irrigated direct from the Nile through the escape. It may be stated, without exaggeration, that the whole of the Yusufi Canal supply which enters Beni-Suef Province before the time of final discharge is wasted. A great part of the basins in an ordinary year receives only four or five days' irrigation with white water, instead of 45 days with rich red water. If the proposed new feeder in the Minia Province were constructed, and a regulator built across the Yusufi Canal opposite the Sultani basin, and another opposite the beginning of the Bahabshin basin, the rents of the dependent basin lands would rise from 1·75*l.* to 3·50*l.* per acre, and the lands themselves in twenty or thirty years would be sufficiently improved to be profitably put under permanent irrigation. Let the Government hand over to Mr. Webb 800,000*l.* for the basins north of Assiout, just as it handed over to Colonel Ross 800,000*l.* for the southern basins, and the country would reap a richer benefit than from twice that sum of money spent in any other manner whatsoever. In this opinion I am confident I have the concurrence of the Irrigation Officers on the spot. To-day, however, the

Government looks on the improvement of basin irrigation as Naaman looked on the washing in Jordan. It prefers bathing in Abana and Pharphar, forgetful of the fact that while disease is present the simpler operation is the more profitable.

The perennially irrigated tracts north-west of Beni-Suef are in great part the property of resident Egyptians, and have, moreover, been gradually changed from basin to perennial irrigation at a rate of 1000 or 1500 acres per annum, so that the proprietors have been able not only to spend all their money on the spot, but also to provide themselves with the stock necessary to properly work such land. The land also is suitable for perennial irrigation and is favourably situated. The presence of large numbers of cattle which compose the stock of the fellaheen, permits of extensive clover cultivation in winter. Clover again improves land; it permits of land being washed where drains are in existence, eats down salts if they are present in small quantities and enriches the soil with nitrates. All these facts have combined to make Beni-Suef the centre of one of the most successful examples of the benefits to be reaped from perennial cultivation. The deterioration so marked in the northern half of Minia is nowhere to be seen. A careful examination of the two tracts will convince anybody of the immense benefits to be reaped from perennial irrigation gradually extended and applied to suitable lands; and the heavy losses to be expected from the same irrigation spread broadcast and applied to unsuitable lands. Here again I am but the mouthpiece of all local officers.

The principal crops are cotton, wheat, clover, sorghum, beans, barley, sugarcane and onions.

The Daira Sania has one sugar factory in this province, viz. Biba. Its sugar capacity in tons is 14,000. The out-turn in 1896–97 was 8900 tons, and in 1897–98 was 7600 tons.

Geeza Province.

Description of Land	Extent in Acres		
	Left Bank of the Nile	Right Bank of the Nile	Total
Basins	80,200	25,400	105,600
Nile berms	57,300	13,200	70,500
Perennial irrigation	6,100	..	6,600
Total	143,600	38,600	182,200

The 182,200, or to speak more exactly, the 182,180 acres in this province are thus subdivided among the different classes of proprietors:—

	acres
Resident Egyptians	127,255
Non-resident Egyptians	38,259
Foreigners	12,202
Wakf	4,464
Total	182,180

The population is 401,634, or 225 per 100 acres.

The mean renting value is 3·40*l.* per acre per annum. The rents vary from 7*l.* to 1·50*l.* per acre. The mean taxes are 1·00*l.* per acre, or 30 per cent.

The left bank of the Nile has 137,506 acres on a length of 95 kilometres,* and the right bank 38,544 on a length of 90 kilometres. The mean width of the cultivated land on the left bank is 5900 metres, and on the right bank 1800 metres. The principal crops are sorghum, wheat, cotton, sugar-cane, clover, melons, onions, barley and beans. All round the site of ancient Memphis are very extensive date plantations.

The enclosed area in this province, which for all practical purposes is the same as perennially irrigated land, is exceptionally high, owing to the inferiority of the basins canals, the proximity of Cairo and the excellent subsoil water, especially since the Barrage was repaired and the water level raised. The spring level, which was originally 5 and 6 metres below the surface, is now from 2 to 4 metres and very convenient for irrigation. The ancient mounds of Cairo provide manures in plenty, and the heavy demands for fodder and milk result in extensive areas being planted with clover. Melons and vegetables of all kinds are extensively sown.

At Ayat is an important pumping station and extensive sugar-cane plantations. The Ayat engine has a horse-power of 400, the discharge is 100 cubic metres per minute, the area capable of irrigation is 4000 acres. At Hawaindia is a sugar factory capable of making 8000 tons of sugar, the out-turn in 1896–97 was 6000 tons, and in 1897–98 was 2500 tons. The sugar factory is attached to the sugar refinery of Egypt. The whole is the property of the Société des Sucreries de la Haute Egypt.

The eastern basin canal is inefficient and the irrigation of great part of the basins is indifferent. Whenever water is available in summer the lands to the east of the Nile should be given perennial irrigation from a pumping station placed at the head of the Khasshab Canal. Basin irrigation on this narrow strip could not be improved. For the tracts on the west of the Nile the Ibrahimia Canal might be gradually extended to the Barrages and the high lands near the Nile provided with perennial irrigation. As all this land is sandy the canal should be everywhere in soil, and the irrigation "lift" in winter and summer. If this were done this part of the province would become, owing to its favourable position, the garden of Egypt.

The Fayûm.—Nominally the whole of the Fayûm is perennially irrigated. The area of the cultivable land is 329,390 acres, but 260,000 acres are alone cultivated. The summer crop covers 70,000 acres, which is but 21 per cent. of the whole area and 27 per cent. of the cultivated area, as against 50 per cent. in the perennially irrigated tract in the Nile valley. The land may be thus subdivided among the different proprietors:—

	acres
Resident Egyptians	160,519
Non-resident Egyptians	51,210
Foreigners	2,539
Wakf	372
Daira Sania Administration	75,686
State Domains Administration	39,074
Total	329,390

* Neglecting the strip of desert north of Rahâwi.

The population is 371,006, or 112 per 100 acres.

The mean rental of the province is 1·70*l.* per acre, with a maximum of 6·00*l.* and a minimum of ·50*l.* The mean tax is ·40*l.* per acre, or 24 per cent. of the rentals.

The principal crops are cotton, sorghum, wheat, beans, clover, barley, reeds for making mats, and melons. There are large areas under fruit trees and vines, while the date palm is very common. Sugar-cane has been tried and been found a failure. The speciality of the province is the growth of the olive tree.

This province has been fully described in the previous chapters both as to its formation and special characteristics. Its development depends on a liberal and early supply of flood water and the doubling of the capacities of the canals. Some of the canals should have their sections trebled. Since the Nile deposit is seldom more than 4 or 5 metres in thickness, and generally very much less, while it overlies as a rule bitter salts, it is very liable to be salted. The perennial irrigation might with advantage be confined to the fertile high-lying plateaus, while the swamped and salted valleys might be reconverted into basins, and the level of Lake Kurûn allowed to rise again to its 1884 level. All this has been fully explained in Chapter V.

The land lying on the severe slopes bordering the lake has deteriorated very considerably wherever the higher lands are heavily irrigated. The only remedy for these lands are deep drains and canals running diagonally to the slopes, and cutting off the lands below them from the excessive saturation originating in the irrigation on the tops of the plateaus. Drains in the direction of the slope are valueless, they do not cut off the saturating waters travelling down the slopes.

The Garak depression, which has deteriorated completely and which cannot be drained by ordinary methods, should have its summer supply completely cut off, and be provided with a plentiful supply in flood by rotation, and a spring supply in winter, also by rotation. During summer the hot Egyptian sun should be allowed to thoroughly dry up the land. Rich crops of sorghum followed by barley and clover would be better than the barren wastes of salt land which alone are met with now.

Behêra.—We have now entered Lower Egypt. The whole area is nominally under perennial irrigation. Of the 734,395 acres of cultivated land in this province, 420,000 acres in round numbers are fully reclaimed and 310,000 acres are under reclamation, while in addition there are 130,000 acres of waste land on which no reclamation has as yet been attempted. It will be noticed that of the cultivated area only 60 per cent. is reclaimed, while of the total area of 860,000 acres of cultivated and waste land only 50 per cent. is reclaimed.

The 734,395 acres of cultivated land may be thus subdivided among the different classes of proprietors:—

	acres
Resident Egyptians	300,990
Non-resident Egyptians	216,586
Foreigners	197,270
Wakf	15,790
Daira Sania Administration	907
State Domains Administration	2,852
Total	734,395

The mean rental of the cultivated area of 734,395 acres is 2·23*l.* per acre, with a maximum of 8*l.* per acre and a minimun of ·50*l.* The mean tax is ·50*l.* per acre, or 22 per cent.

The population is 631·225, or 85 per 100 acres.

The principal crops are cotton, rice, clover, Indian corn, wheat, barley and beans, while date palms are very plentiful in the north.

South of the sand dunes bordering the Mediterranean there used to be three lakes, Abukir, Edku and Mareotis. Lake Abukir has been drained by an English company and is being gradually reclaimed; Lake Edku is being gradually dried up by the Government to allow of the drainage cuts tailing into it having an efficient outlet; and Lake Mareotis has had powerful pumps erected on it to maintain its level at 2 metres below mean sea. These measures are detailed in the chapter on drainage and land reclamation. The present areas of Lake Edku and Mareotis may be taken as 60,000 and 70,000 acres respectively, making a total of 130,000 acres. Lake Edku has an outlet into the Mediterranean at Madia.

The Behêra Province has two strips of very good land in addition to the rich lands at the south-east corner, but the province generally is poor and needs considerable sums to be spent on its development. The best land follows the line of the ancient Canopic branch of the Nile with its head of Kafu Bolin. The trace of the Canopic branch can be easily followed down the Abudiab Canal past Saft el Muluk to Dinshal, Karakas, Gattâs and Karioun, finally tailing into Abukir Bay west of Madia. When the Katatbeh Canal was remodelled, it was unfortunate that its new alignment was not taken down this line to Damanhour. Its present channel on either side of the railway is an unfortunate one, as it is taken in high embankment across the drainage of the country, and the only place where it is in digging is where the railway passes close to the ancient Canopic branch. All drainage east of the Canopic branch goes naturally to lake Edku, and all drainage west of the Canopic branch goes naturally to Lake Mareotis. The second strip of good land follows the line of the Rosetta branch of the Nile. No canal in this province except the Mahmudia has an escape, so that it is very unfortunately situated in that respect. The drainage has been most thoroughly and efficiently taken up, but drainage cuts without escapes for excess canal water are of no permanent value.

The irrigation of the province is effected by three main canals, the Rayah Behêra from upstream of the Barrage, the Katatbeh from a point some 45 kilometres down the Rosetta branch, and the Mahmudia Canal from a point 40 kilometres south of Rosetta. The Rayah Behêra supplies the water in summer and winter, while the other two, principally the Katatbeh, in flood. Details and discharging capacities of these canals are given in Chapter VI. The Mahmudia Canal was dug by Mehemet Ali in 1819–20 with the object of opening a direct waterway between Cairo and Alexandria, supplying the latter town with water, and providing for summer irrigation. This canal was fed in a novel way. An area of 60,000 acres to the south of Atfeh was surrounded by a dyke, filled with water from the Nile in flood between the month of August and October, and turned into a reservoir for supplying winter and summer water to the Mahmudia Canal. Owing to the shallowness of the reservoir, the short interval of time within which it could be filled, and the long interval of time it had to be drawn upon, with all the waste of evaporation and absorption through nine months of the year, the reservoir was found to be insufficient, and in 1849 it was replaced by pumps at Atfeh and Katatbeh, already described in Chapter VI.

This province has been in the past an excellent example of the costliness of pumping into the main feeder canals from the Nile in summer, instead of building permanent weirs across the Nile and taking the water by gravitation. The advantages claimed for pumping were :—

1. No necessity for dredging the canals, as the water would enter at a high level from the pumps.

2. Flush irrigation in summer.

3. The certainty of the pumps as compared to the weirs.

On the matter of cost there was never any question, for the supply of 50 cubic metres per second by pumping into one province in summer cost the State 50,000*l.* per annum in round numbers, and the cost of raising the 400 cubic metres per second needed for Lower Egypt would have amounted to 400,000*l.* per annum. Weirs can be built on the Nile for 800,000*l.* apiece, and if Egypt had had no weirs, two such weirs could have ensured the whole supply being utilised with an annual outlay of 15,000*l.* Interest on 1,600,000*l.* at 5 per cent. would have represented 80,000*l.* per annum, and maintenace 15,000*l.*, bringing up the total to 95,000*l.* per annum as against 400,000*l.* per annum for pumping. The question in Egypt, however, was much simpler, for the hitherto condemmed weirs known as the Barrages existed, and Sir Colin Scott-Moncrieff had them repaired by Colonel Western for 500,000*l.*, and so secured summer irrigation to Lower Egypt at a prime cost of money only slightly in excess of what would have been the annual outlay on pumping.

It was found in Behêra that there was no diminution in the money spent on dredging, as the dredging of the three canals was as necessary as ever on account of navigation, water supply in winter, and the fear of allowing silt to accumulate. The perpetual dredging of the canals prevented flush irrigation in summer in their upper reaches, while in their lower reaches they give as much flush irrigation today, now that they are fed by gravitation, as they did in the old days of pumps. General flush irrigation in summer is however a curse and not a blessing. Looked at from the point of view of security, weirs have proved themselves to be as reliable as the gigantic pumps required to lift the quantities of water needed for important irrigation canals irrigating a million and a half of acres between them.

Appendix III. contains a most interesting report by Mr. Verschoyle, Inspector of Irrigation on the province of Behêra. It, unfortunately, arrived too late to be inserted here.

Menoufia.—The whole area of 351,596 acres is under perennial irrigation, fully reclaimed and fully cultivated.

This area may be thus subdivided among the different classes of proprietors :—

	acres
Resident Egyptians	290,764
Non-resident Egyptians	44,226
Foreigners	14,492
Wakf	2,023
Daira Sania Administration	91
State Domains Administration	0
Total	351,596

The population is 864,206, or 245 per 100 acres.

The mean rental is 5·83*l.* per acre, with a maximum of 8*l.* and a minimum of 3*l.* The mean tax is 1·53*l.* per acre, or 26 per cent. of the rents.

The principal crops are cotton, Indian corn, wheat, clover, beans, barley, vegetable and fruit gardens.

The proportion of resident proprietors is large, the population dense, the land rich, cattle plentiful, and the cultivation superb. One of the most prosperous agricultural communities in Egypt inhabits this province. The irrigation is generally lift through winter and summer, and the soil has not in consequence deteriorated.

This province is well provided with canals, and as they are generally in soil in winter and summer, no drainage cuts are needed and none exist. Deterioration of soil has begun in a few places where irrigation has begun to be flush throughout the year, but such areas are small and could very easily be given that lift irrigation which is the life of the province.

Garbia.—The whole area is nominally under perennial irrigation. Of the 1,077,047 acres of cultivated land in this province, 790,000 acres in round numbers are reclaimed and 290,000 acres are under reclamation, while in addition there are 190,000 acres of waste land on which no reclamation has as yet been attempted.

The 1,077,047 acres of cultivated land may be thus subdivided among the different classes of proprietors :—

	acres
Resident Egyptians	371,078
Non-resident Egyptians	261,055
Foreigners	208,449
Wakf	34,400
Daira Sania Administration	15,084
State Domains Administration	186,981
Total	1,077,047

The population is 1,297,656, or 120 per 100 acres of cultivated land.

The mean rental of the cultivated area of 1,077,047 acres is 3·10*l.* per acre per annum, with a maximum of 8*l.* per acre and a minimum of ·50*l.* The mean tax is ·82*l.* per acre, or 27 per cent.

The principal crops are cotton, clover, wheat, Indian corn, rice, barley and beans. The southern parts of the province are similar to Menoufia, but in the north the only really important crop is cotton, and everything is subordinated to it.

South of the sand dunes bordering the Mediterranean lies Lake Borillas with a permanent area of 180,000 acres. During flood the lake rises and floods the adjacent country. The opening into the sea is near the town of Beltim. The question of the lake is discussed in the chapter on Drainage and Land Reclamation.

The northern half of this province is very difficult to irrigate in summer, as all the canals which supply it with water have to run the gauntlet of the wealthy and serried proprietors of Menoufia and of southern Garbia itself. Much money has been spent in widening and deepening some of the main canals, but very much remains to be done. All the main canals should be given such sections that they might easily carry their winter and summer supplies in soil, and so ensure the irrigation of the north without injury to the rich middle strip of the province, which was more prosperous and wealthy in the old lift irrigation days than it is to-day

In addition to this widening and deepening of the canals, especially the great central artery the Kasad Canal, the Damietta branch should be provided with a weir or barrage at Samanûd and a secondary feeder taken to the Bahr Shebîn downstream of Rahbain regulator. This increased supply might be put in communication with the central part of the Delta in the extreme north by means of a special canal connecting the Bahrs Tira and Mallah, north of Abshan. A suitable work could be built at Samanûd for 350,000*l.*, which would not only utilise the 20 cubic metres per second of subsoil springs which filter into the Damietta branch, but also pass directly to the thirsty lands in the north the summer supplies needed for them without unduly filling the existing canals in their upper reaches in Menoufia and southern Garbia. As no sound and reliable work could be built in the Rosetta branch near the sea under an expenditure of 750,000*l.*, it would be better to continue the construction of the temporary earthen dam on this branch at Mehallet Amir, which can be done for less than 10,000*l.*, and which is not needed every year. The rising flood sweeps away and obliterates all trace of this dam every year that it is constructed.

Most of the canals are well provided with escapes, and the distribution of red water in flood is generally satisfactory. The department has recently begun a system of weekly rotations in winter and summer, which will do an immense amount of good if rigidly enforced and if the canals in the middle reaches have their sections increased. There is no fear of such canals silting in their sections in flood if the escapes are kept fully open.

The drains are subdivided into twelve systems, and generally follow the depressions between the deltaic canals. In the north-east of this province there is a large area of waste land which is never covered in flood. This land has in great part been gradually converted into a salt plain, from which the salts are carried by the prevailing north-west winds on the lands lying immediately south of them. The reclamation of these latter lands is in consequence very difficult, and will never be accomplished until the salt plains have been covered by water. This point might be remembered when the drying up of Lake Edku is considered.

Kalyubia.—The whole area of 191,843 acres is under perennial irrigation, of which all but 10,000 acres are fully reclaimed and fully cultivated.

This area may be thus subdivided among the different classes of proprietors :—

	acres
Resident Egyptians	106,754
Non-resident Egyptians	71,158
Foreigners	13,539
Wakf	347
Daria Sania Administration	25
State Domains Administration	0
Total	191,843

The population is 371,465, or 193 per 100 acres.

The mean rental is 5·60*l.* per acre per annum, and the mean tax 1·43*l.* per acre, or 26 per cent.

This is another province where the irrigation in winter and summer is generally light, and the land in consequence in excellent preservation. The same remarks

apply to it as to Menoufia, only in a more moderate degree, because the proportion of resident proprietors is not nearly so large.

Sharkia.—The whole area is nominally under perennial irrigation. Of the 568,484 acres of cultivated land, 440,000 acres in round numbers are reclaimed and 130,000 acres are under reclamation; while in addition there are 140,000 acres of waste land on which no reclamation has as yet been attempted.

The 568,484 acres of cultivated land may be thus subdivided among the different classes of proprietors:—

	acres
Resident Egyptians	355,552
Non-resident Egyptians	176,787
Foreigners	29,618
Wakf	2,560
Daira Sania Administration	3,967
State Domains Administration	0
Total	568,484

The population is 749,130, or 131 per 100 acres.

The mean rental of the cultivated area of 568,484 acres is 3*l.* per acre; and the mean tax is ·75*l.* per acre, or 25 per cent.

Between the provinces of Sharkia and Dakalia on one side and the sand dunes bordering the Mediterranean on the other lies the Menzaleh lake, with a permanent area of 490,000 acres. The opening into the sea is at Gemelah, west of Port Said. During flood the lake rises and floods the adjacent country. The question of the lake is discussed in the chapter on drainage and land reclamation.

The principal crops are cotton, clover, wheat, Indian corn, rice, barley, beans and ground nuts. The date palm is very extensively cultivated along the edge of the desert.

The summer supply of this province has very considerably benefited from the Barrage repairs. The new Rayah Tewfiki, constructed by Colonel Western, supplies this province and Dakalia with a very liberal supply of water. Extensive areas of sandy desert have been recently reclaimed and planted with ground nuts. With the liberal supplies sent down the canals all the high-lying lands have greatly benefited, but much of the low-lying land has deteriorated. The area irrigated from wells in this province was very extensive in the past, as the desert sand is close to the surface and buried under insignificant depths of clay over large tracts. The high-level perennial canals have damaged the whole of this land. To enable this province to enjoy the full benefits of perennial irrigation, every canal should, I think, be provided with free flow in flood, and widened and deepened in its middle reaches, escapes should be multiplied everywhere, and the summer supplies kept in soil wherever possible, with rigid weekly rotations through the winter and summer. The Wady Tumilât near Tel el Kebir, which has been almost irretrievably ruined by the high-lying Ismailiah Canal, constructed by the Suez Canal Company, gives warning of the damage which can be done by high-lying perennial canals in unsuitable soil. If the canals, which are I think the real source of the harm, were looked to and scientifically treated, three-quarters of the drainage cuts might not be needed at all.

The drainage cuts in this province are very plentiful, but there is a lamentable lack of red water in flood at the tails of nearly all the canals. If the extensive salted lands in the north of the province are ever to be reclaimed, the amount of red water reaching them must be multiplied by 10.

Dakalia.—The whole area is nominally under perennial irrigation. Of the 514,462 acres of cultivated land, 450,000 acres in round numbers are reclaimed and 60,000 acres are under reclamation; while in addition there are 40,000 acres of waste land on which no reclamation has as yet been attempted.

The 514,462 acres of cultivated land may be thus subdivided among the different classes of proprietors:—

	acres
Resident Egyptians	229,465
Non-resident Egyptians	212,746
Foreigners	56,149
Wakf	1,518
Daira Sania Administration	11,507
State Domains Administration	3,077
Total	514,462

The population is 736,708, or 140 per 100 acres.

The mean rental is 3·0*l.* per acre per annum, and the mean tax is ·94*l.* per acre, or 31 per cent.

The principal crops are cotton, rice, clover, wheat, Indian corn, barley, beans, and vineyards in the S.W.

The remarks which have been made about Sharkia apply to the southern half of this province, especially to the tracts on the Khazzan and Bohya canals. The country wants escapes for red water rather than drains. The Bahr Sogair, in the north of the province, is an excellent example of a canal with free flow in flood and general lift irrigation in winter and summer. The finest crops in the province and the best preserved lands are met with on its banks. It is in every way a striking contrast to the Bohya, where exactly the opposite conditions prevail. The water surface of the Bohya might be lowered 2 metres in summer and 1 metre in flood with the greatest advantage. The upper reaches of the Tanah and Gabbada deltaic canals, occupying the highest lands in their neighbourhood, with the Tanah-Gabbada drain between them occupying the lowest land, is one of the best examples in Egypt of well-designed canals and drains in their proper positions. The lower reaches of these canals have been converted into drains with disastrous consequences. Colonel Ross' saying of a red-water famine being the greatest calamity which can overtake any part of Egypt, might be posted with advantage in every inspector's office in the country.

Take the whole of the basin tracts of Egypt, and compare them with the perennially irrigated tracts, and we are met with the startling fact that there is not between the renting values a greater difference than 15 per cent. This is doubtless due to the fact that basin irrigation, imperfect as it is in places, has attained a far higher degree of perfection than perennial

irrigation. The perfection of perennial irrigation and its scientific treatment on lines such as those attempted to be traced by me in this book, are the problems which the Irrigation Department has to solve. If it cannot solve them within a reasonable time, the improvement of large areas of favourably situated land to whose amelioration still larger areas of land unfavourably situated have been sacrificed, and the reclamation of extensive wastes at the high price of the permanent abandonment of still more extensive wastes which basin irrigation could easily have reclaimed, will bring us face to face with the fact that the basin irrigation of Egypt, devised by the ancient Egyptians themselves thousands of years ago, and in full vigour to-day, was better suited to the country and had more permanency than the system of perennial irrigation, whose mushroom growth has had the whole strength of the Government on its side, but has had Nature against it.

CHAPTER VIII.

DRAINAGE AND LAND RECLAMATION.

Recapitulation of land formulation and classification of land—Results of the introduction of basin irriga ion—Drainage of the flat lands in the southern half of the Delta—Drainage cuts not necessary in such tracts—The deltaic formations of the north—Faulty and correct methods of drainage—Necessity for escapes as great as for drains—Method proposed for gradually introducing lift irrigation in the flat lands of the south—Details of drainage construction in the deltaic tracts—Capacity of drains—Necessity for lifting drainage water into the drains—Lift and flush irrigation by rotation—Inlet pipes into the drainage cuts—Clover washings—Drainage channels dredged into the lakes—Methods of clearing the drains of weeds—Bridges—Pipe crossings—Cost of thoroughly draining and providing escapes for Lower Egypt—Subdivision of land in Lower Egypt, according as it is waste, or reclaimed or under water—Description of the existing waste lands of Egypt—The openings into the sea of the great lakes—Causes of deterioration of land—Areas of lakes and their water levels—Drying the lakes—Effect on the openings into the sea—Fishing revenue—Reclamation by basin irrigation in Mehemet Ali's day—Mr. Frank Hazeldeen's experiment—Mr. Aubert of the State Domains—Proposed basin reservoirs in the Berea—Lake Abukir—Mr. Sheppard's paper on The Reclamation of Lake Abukir—Cost of pumps—Experiment on pumps—Method of irrigation and drainage—Salts in the soil—Cost and results of reclamation.

IT has been already stated that the formation of Egypt is deltaic, modified by basin irrigation in the whole of Upper Egypt and in the southern half of Lower Egypt. The northern half of Lower Egypt is the true deltaic formation, which consists of high-lying canals or branches of the river with intervening depressions. The line of villages separating the flat basin-formed lands of Lower Egypt from the lands of deltaic formation has been given in great detail in Chapter VI. The main villages and towns on this line may be recapitulated here. They are Delingat, Damanhûr, Shibrakhêt, Sanhur el Medina, Nashart, Mehalla Kobra, Nabaroh, Mansûra, Simballawein and Fakûs.

In Chapter VI., moreover, the land of the Delta was divided into four main classes.

1. The dense black clay soil of a depth of over 6 and 7 metres.

2. A dense black clay for a depth of from 1 to 3 metres from the surface, overlying sand.

3. A sandy clay, chiefly to be met with on the berms of the Nile and all the branches and natural canals.

4. Sand.

The basin tracts are principally composed of the first and second classes, with a small proportion of the third class near the canals.

The deltaic tracts are principally composed of the third and first classes; the first class in the valleys and the third class near the canals.

In many parts of the Delta the desert sand comes to the surface, and is nowadays cultivated over extensive areas.

In the preceding chapters much has been already written on the subject of drainage, which may be briefly capitulated here.

"The introduction of perennial irrigation into any tract in Egypt means a total change in crops, irrigation, and indeed everything which can affect the soil. Owing to the absence of rain, the land is not washed as it is in other tropical countries, unless it is put under basin irrigation. An acre of land may receive as many as twenty waterings of about 9 centimetres in depth each, i.e. a depth of water of 1·80 metre per annum, which is allowed to stand over the soil, sink about half a metre into the soil, and then be evaporated. Since the Nile water, especially in summer, has salts in excess, these salts accumulate at the surface, and if not eaten down by suitable crops, soon appear as a white efflorescence. While the spring level is low, capillary attraction cannot bring up to the surface the spring water, which generally contains a fair proportion of salts; but where the spring level is high, the salt-carrying water comes to the surface, is there evaporated, and tends to further destroy the soil. In old times the greater part of the cultivated land was under basin irrigation, and was thoroughly washed for some fifty days per annum; while the rest, consisting of the light sandy soils near the Nile banks, was protected by insignificant dykes, which dykes were burst every very high flood, and thus allowed the land to be thoroughly swept over by the Nile and washed once every seven or eight years. All this is at an end now in the tracts under perennial cultivation, and other remedies have to be found."

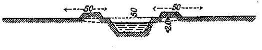
We shall first consider the old basin tracts south of the line of villages already given, and where we have to do with what are practically flat surfaces. In this area canals, whose water surface in winter and summer is 1 metre and more below the surface of the country, have caused no inconvenient rise of spring level, and the country is rich and prosperous to whichever class of land it may belong. Where, however, we have to do with canals which run above the level of the country throughout the year, the spring level has risen inordinately. The dense clay soils have been injured over very limited areas, but where such soils have become salted, the deterioration has been very pronounced, and reclamation will be slow and stubborn. In the clays of shallow depth overlying sand (when the country



was formerly irrigated from numerous wells which drew their water from the sandy substratum) perennial high-level canals have so raised the spring

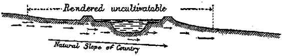
level that what were once some of the richest tracts in the Delta are to-day salted plains or rice fields. In the sandy clays also, canals carrying water above the surface of the ground throughout the year have produced considerable deterioration of the soil. Flush irrigation in the sandy tracts has resulted in the water filtering through the sand and destroying the rich clay soil around.

In these flat plains without appreciable valleys and depressions, drainage cuts affect a small area on either side of the drain, and are as a rule valueless except where they traverse single properties and are complemented by a network of private drains. Where such drains traverse the small holdings tracts they are quite valueless. Their presence has no effect on the subsoil water as they are far too shallow, and the small proprietors prevent each other from making any use of them for surface drainage.



Such drains have their water surface seldom more than 50 centimetres below ground level, and where they are used liberally they generally run brim full, choked with weeds and rushes.

In these flat level tracts the true and only real remedy is to be found in deep capacious canals, giving flush irrigation in flood, and running well below soil in winter and summer. Lift irrigation costs from 1*l.* to 2*l.* per acre, but gives from 2*l.* to 4*l.* per acre extra yield, and rents are higher, and proprietors more prosperous when the canals are in soil than when they are above ground level throughout the year. This point is so important that it cannot be too often insisted on. We have so far dealt only with well-aligned canals which follow the natural slope of the country. We now

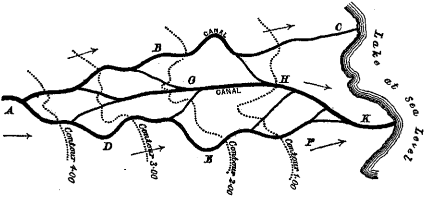


come to defectively aligned canals. Such canals in the tracts we are now considering generally follow the borrow pits of the railways and run across the natural slopes. They are accompanied by belts of bad salted land on both sides where they are permanently above the level of the country. Such canals should always be provided with drains when they are permanently above the level of the ground. These drains should be tailed into the nearest drainage cuts. The canals should be invariably between the

drains and the railway. Where the drains are between the canals and the railway, as shown in the figure, they are of little value.



The conditions prevailing in the deltaic formations north of the line of villages already given are very different from those just considered. Here we have decided depressions between the natural canals.



A B C and A D E F are main branches taking direct from the river.
G H K is a subsidiary branch into which all the escape water flows, and which is itself deltaic.

Here drains are both necessary and effective ; there are depressions and slopes in both longitudinal and transverse directions, and surface drainage



is effective and helps to lower the spring level of the higher lands, which are generally a sandy clay while the valleys are of a dense clay.

The small holdings tracts are few in number, and large proprietors are the rule. Moreover in these tracts the fellaheen have been accustomed to drainage for generations, and help one another instead of impeding one another, as they do in the old flat-basin tracts where drains are the creation of yesterday.

The subsidiary canals like G H K are escapes, and are as necessary for healthy irrigation as the canals themselves.

Now such tracts can be drained in two ways. They can be treated as on Fig. A, where the canals and escapes *A B C*, *A D E F* and *G H K*, widened and deepened where necessary, are allowed to exist and perform their proper functions in allowing a free flow of the rich red fertilising waters of the Nile flood, which can be used for irrigation and warping; while the two drains *a b c*, *d e f g h*, aided by minor branch drains if necessary, follow the very lowest levels of the depressions and cross the minor canals by syphons. Canals, escapes and syphons are all kept separate. The irrigating channels are on the highest lands and the drains in the lowest. This method of treatment is natural, is healthy, and should, in my opinion, be followed everywhere. The only occasion on which it might be

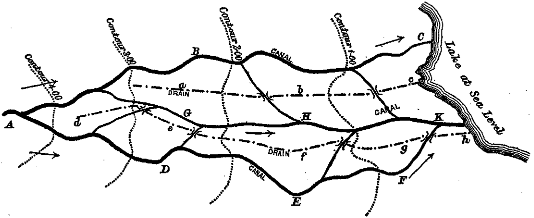


FIG. A.—PERFECT DRAINAGE AND IRRIGATION.

A B C and A D E F are main branches, taking direct from the river.

G H K is a subsidiary branch, into which all the escape water flows, and which is itself deltaic.

a b c and *d e f g* are drains in the lowest lands, crossing the main canals by syphons.

permitted to use an ancient and natural canal for a drain is when the canal splits into two on the very edge of the lake, and where one of the branches traverses swamps and marshes without any cultivation, and the other traverses cultivated lands and is capable of carrying the supply. Such opportunities are very rare indeed, but they do exist. An example exists at the tail of the Bahr Mallah, where one branch has been utilised for the tails of drainage, cuts Nos. 5 and 6. Even here, however, separate drains would have been better, as the Berea needs red water almost more than it needs drainage.

The other way of treating such tracts is depicted on Fig. B. Here there is no free flow of the flood water, as the whole of the subsidiary canal

or escape has been made into a drain, and moreover the tails of the main canals have been treated in the same way. Dams have also been put into the minor canals at C, F, G, H, K, L, M, N. The lower reaches of what are canals to-day are stagnant pools of white water, the upper reaches of the canals are silt traps for all the fertilising mud the water contains. As there is no power of escaping freely the excess water of the canals at these tails, the main canals gradually dwindle into minor canals in size or are maintained at an unnecessarily high level in flood, while the minor canals

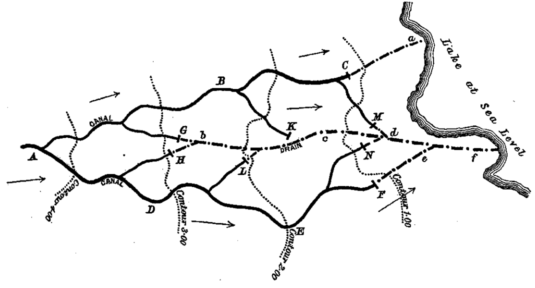


FIG. B.—INDIFFERENT DRAINAGE AND IRRIGATION.

A B C and A D E F are main branches taking direct from the river, and dammed at C and F, with their lower reaches *a* and *e f* turned into drains.

G, H, K, L, M, and N are minor canals dammed at their tails.

b c d f is a subsidiary branch turned into a drain, and allowed no longer to carry escape water from the main or minor canals.

become more and more insignificant, and August rotations become quite a feature of the irrigation system. And as it is impossible to hermetically seal all the canals in flood, the excess water is run through the fields and down watercourses into the nearest drains, hurting the lands so traversed. The fact that the main drains do not occupy the lowest lands renders necessary an excessive annual expenditure on their deepening and widening, which in some cases exceeds the cost of independent drains traversing the lowest lands, as shown on Fig. A. Energetic landlords who occupy

favourably situated holdings thoroughly irrigate and drain their lands, monopolising in great part drains and canals, but this is done to the detriment of the low lands and to a general deterioration of the whole tract. In the early days when the department was face to face with unmanageable canals overflowing their tail reaches in flood, and with a restricted budget which neither permitted of deepening and widening the canals at their tails nor of digging drains of any capacity, it was an economical way of overcoming the difficulty to convert many of the canals into drains and restrict the supply entering the others. Time, however, has brought out all the faults of the system, and now that the Caisse of the Public Debt is giving hundreds of thousands of pounds per annum for drainage it would be statesmanlike to return to the best and most scientific method, and have both drains and escapes as depicted on Fig. A. The fact that all the canals which have been converted into drains have been considerably widened and deepened would render them most efficient escapes, and the heavy expenditure incurred in this direction would prove itself some of the best spent money of the last ten years.

Considering that proper systems of low-level canals, giving flush irrigation in flood and lift irrigation in winter and summer, have shown themselves thoroughly capable of irrigating the flat basin-formed tracts without any recourse being had to drainage cuts, and that the lands so irrigated have always paid the highest rents, such systems should always be put before themselves by the engineers as final goals. As, however, the wholesale introduction of such systems on lands which have had perennial flush irrigation for the last ten years would be too drastic a measure, the best method of procedure would be to utilise the weekly rotations where the canals give flush irrigation one week and lift the next. The landowners will never be content to allow the water to flow past their fields for half the year without lifting it, and they will gradually acquire the means of lifting it, and so by degrees the canals might be made to give flush irrigation for six days and lift for eight, and so on until the final goal of perpetual lift irrigation in winter and summer was reached. If this procedure were rigidly adhered to, no drains would be necessary in these tracts, and gradually the recently constructed drains would be profitably converted into escapes for excess water in the canals. The money now spent on drains would, I think, be better spent in widening and deepening canals and escapes. On all lands which are changed from basin to perennial irrigation, if care were taken that no new tracts were given flush irrigation throughout the year, there would be no undue hasty development without any permanency about it. The proprietors would gradually avail themselves of this irrigation as they had the means to buy cattle or pumping engines, and there would be steady and sure improvement of the whole area instead of as at present, mushroom improvement of part and permanent deterioration of part.

We have now finished with the flat, basin-formed lands. In the *true deltaic lands* to the north of the Delta, drainage cuts will always be a necessity, and it is only to such lands that the following *details* of drain construction can be applied :—

"For reasons given in the chapter on agriculture it would be advisable to design new drains, with a section capable of discharging a minimum of 1 cubic metre per second per 10,000 acres for lands under dry crop, and a minimum of 1 cubic metre per second per 6500 acres of rice.

It has been the habit hitherto to construct the drains of comparatively small capacity at first, to throw the spoil well back, and gradually increase the channel as cultivation extended and the quantity of water needing removal became more considerable. An attempt has also been made to keep the drains of such a section that the drainage water will be in soil, but the amount of water which can be discharged from rice fields and land under reclamation is so enormous that there will never be any limit to the size of the drains. The time has surely come for the department to construct its drains of suitable section, to meet a fixed discharge whether in soil or out of it, and to provide the drains with solid substantial banks, leaving the proprietors to drain by gravitation if they can, and if they cannot to drain with pumps. A man who has flush irrigation for his fields as a rule, should consider himself fortunate if he can drain off *all* his surplus water, be it by pumping or by gravitation. As the water which should be drained off the field in order to ensure a good and healthy crop should be one-third the water needed for irrigation, it will readily be seen that it is far more convenient for cultivators in the dense clay soils which constitute the valleys of all the deltaic formation to have flush irrigation and lift drainage, rather than lift irrigation and flush drainage. For it must be remembered that in the tracts to the north of the line so often spoken of, where the deltaic formation is well developed and the country provided with both longitudinal and transverse slopes, the sandy clay soil is confined to small strips bordering the canals, and lying at a level well above the dense clay soil which monopolises the whole of the valley, and especially the lowest parts where the drains should be. In all these tracts the canals can be run at such a level that the sandy clay strips will receive lift irrigation, and the whole of the rest of the valley flush irrigation throughout the year, by direct flow in flood and with the aid of regulators and rotation in winter and summer. Flush irrigation and lift drainage under these conditions can do no harm to these clay tracts provided the canals all run freely and fully in flood when they are charged with the rich muddy waters of the Nile, and the drains are well designed down the bottoms of the depressions. Drains which to-day are capable of but indifferently draining very limited areas, where favourably situated landed proprietors on the banks can discharge any quantity of water they like into them, will be capable of thoroughly draining far larger areas when the water discharged into them is by lift and consequently restricted to the actual requirements of the lands.

In the above paragraph I have recommended flush irrigation by rotation in winter and summer only and by free flow in flood. In the first edition of this work I recommended rotations in flood, but after a careful examination of these lands through the two floods of 1895 and 1896 in localities where the flood supplies were

much restricted, I have learnt to deprecate such action. The lands need every drop of red muddy water which they can get, and the proper procedure is, I think, to increase the canals when necessary, but let them run freely every day of the red water supply. While making these inspections I was daily reminded of the truth of Colonel Ross' remark already quoted, that the greatest calamity which can overtake any part of Lower or Upper Egypt is a red water famine. Such a famine exists to-day in many places.

When the drains traverse high lands, as they do at every minor canal crossing, the banks of the drainage cuts should be provided with iron pipes to limit to their minimum requirements the water which will be discharged freely into the drains. Some excellent examples of this procedure are to be seen on some of the First Circle drains constructed by Mr. Garstin.

Previous to the great distribution and sale of waste lands in Egypt in 1884, the high lands near the canals in the north were alone cultivated, and then drainage water was poured freely over the lower lying wastes. The handing over of these wastes to influential bodies and persons without in any way conserving drainage rights for the existing cultivation has caused the ruin of many smaller proprietors and the deterioration of much good land. These lands have a first claim on the Government.

It is a fact generally admitted in Egypt that *washings* of the land in winter are far more effective than in summer, some say, because the water is clear in the winter, and capable of dissolving the salts; others say, because the water is cold in winter. Any way, even where crops are grown, drains can do much good by permitting of the systematic washing of the clover fields in winter. Indeed, some good agriculturists prefer keeping their lands free from salt on this method, to resorting to the more costly and difficult cultivation of summer rice. This last statement of course applies to lands which are capable of producing fairly good clover.

All drainage channels which flow into the lakes should be well dredged into the lakes so as to induce a good flow, and each of the main drains of any magnitude should be provided with a grab dredger to keep them clear of weeds and rushes.

It is of no use tailing a drainage cut into the sea through the sands dunes. The storms which accompany the north-west winds, when they blow strong, obliterate the drains. All drains should either be tailed into the lakes or into the openings kept clear by the main branches of the Nile in flood.

Drains carrying clear water, as they generally do, are very liable to become full of weeds and rushes. Grab dredgers have already been recommended for the main drains. Where possible, the construction of temporary dams for a limited time in summer, and the entry of salt water in the drains is very destructive of fresh-water plants. For the smaller drains the best procedure is to put in temporary dams, dry the different reaches of the drains one by one, and weed clear the beds and sides.

On all drains, wooden or iron bridges supported on masonry abutments raised well above damp and saturation level should be most liberally provided for all road crossings. If bridges are not constructed at all the crossings, the villagers throw in cotton stalks to obtain a firm footing for their cattle, and often hold up as much as a foot of water at each place. As $\frac{1}{30000}$ is an ordinary slope for the drains, it will readily be seen how harmful such obstructions are.

For irrigation channel crossings, wrought-iron pipes made of plates from $\frac{1}{8}$ inch

to ⅜ inch have been found the more suitable. The diameters vary from 10 centimetres to 1·50 metre. Such pipes can be transported far more easily than cast-iron pipes; and those which have been buried underground for upwards of 15 years show as yet no appreciable deterioration."

I have estimated in great detail the cost of introducing into the provinces of Garbia and Dakalia systems of drains and escapes which would ensure free flow of red water to every canal and drainage for every depression. For the provinces of Behêra and Sharkia I have calculated the cost by analogy. The results have worked out as follows:—

Garbia	£420,000
Dakalia	390,000
Sharkia	450,000
Behêra	350,000
Total	£1,610,000

A grant of 300,000*l.* for five and a-half years would suffice to put the drainage system of Lower Egypt on a healthy basis. As the area to be drained covers 1,300,000 acres, this sum represents an expenditure of 1·25*l.* per acre.

Having finished with the principles on which the main drainage of the Delta should be undertaken and which interest the State, we now come to the details which concern individual proprietors, and which may be called land reclamation. I personally consider a wholesale return to basin irrigation as the true solution of the problem of reclaiming the waste lands of the Delta, but for many years to come the State will continue its present policy of wasting the flood waters of the Nile and doing what it can with the summer supplies alone; and consequently reclamation by wholesale basin irrigation will be outside the field of practical politics. The Government will not undertake it, and it will be beyond the capacity of private individuals and syndicates.

Before entering into the details of reclamation, I shall describe the character of the lands with which we have to do.

There are, as has been already stated, 800,000 acres of land undergoing reclamation and 500,000 acres of waste land which have not yet been touched. There are moreover 380,000 acres of land flooded by the lakes from September to December and exposed in summer. These areas may be subdivided as follows between the three circles of irrigation. It will be remembered that the Third Circle comprises Behêra, the Second Circle Menoufia and Garbia, and the First Circle Kalyubia, Sharkia and Dakalia:—

SUBDIVISION OF LAND IN LOWER EGYPT, IN ACRES.

Circle	Cultivated Area			Waste	Lakes			Total Area, Including Lakes
	Reclaimed	Under Reclamation	Total		Flooded in Flood and Early Winter	Under Water all the Year Round	Total	
3	420,000	310,000	730,000	130,000	..	130,000	130,000	990,000
2	1,140,000	290,000	1,430,000	190,000	180,000	180,000	360,000	1,980,000
1	1,070,000	200,000	1,270,000	180,000	200,000	490,000	690,000	2,140,000
Total	2,630,000	800,000	3,430,000	500,000	380,000	800,000	1,180,000	5,110,000

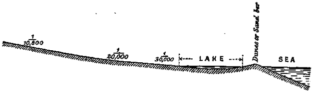
The 800,000 acres of land under reclamation and the 500,000 acres of waste lie generally to the north of the reclaimed land. Further north lie the 380,000 acres of land flooded by the lakes, and then the lakes themselves. Between the lakes and the sea are sand dunes or bars, and in places extensive plains of sand covered with saline shrubs. When the slopes are pronounced the land consists generally of salted clay with scarcely any vegetation; where the slopes are gentle and fresh water can lodge and stagnate, the land is generally marsh or covered with weeds and coarse grasses.

In Ptolemaic and Roman times the whole of this land known to-day as the Berea (plural Berâri) or waste land, was cultivated. The wilderness bordering the lakes was known as the "Ard zafrân," or choice land.

According to local tradition, partially confirmed by the presence of Pharaonic summer canals and cyclopean dykes, some of these tracts were once covered with vineyards, while the rest were divided into enormous basins of some 50,000 acres each and planted with wheat. They are credited with having supported a dense population. They are now a barren plain, from which rise numberless mounds strewn with bricks and pottery.

When the lands were under cultivation the sand bars between the sea and the lakes must have been pierced by numerous openings, through which the flood waters poured during the yearly inundations. The quantity of water discharged into the lakes on the emptying of the Lower Egypt basins must have been over a hundred times as great as it is now. Owing to these numerous and capacious openings, the lakes were kept on the level of the Mediterranean, and prevented during storms from overflowing the lands to the south by very powerful dykes. Gradually, however, as basin irrigation was abandoned and perennial irrigation introduced, the discharge

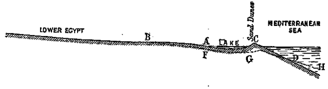
entering the lakes decreased, and the openings diminished in number and capacity, while now each lake has but one opening, and its area is dependent on the quantity of water which has to force its way through it. If the quantity is large the opening is wide and deep, and cannot be obliterated by the periodically strong north-west winds filling it with sand; if, on the contrary, the discharge is feeble, the opening is insignificant and can be obliterated by sand. If an opening is ever obliterated by sand and the sand well piled up by strong winds, the lake in flood has to rise to a



considerable level before it can cut its way through the sand. This rise was so serious in 1890 in Lake Borillos that the water threatened the cultivated lands and the opening had to be artificially begun. As the difference in water level was great the opening was soon widened and deepened by the action of the water itself. The capacity of the water for scour depended, however, solely on its head. To keep these openings clear with feeble supplies of water and without permitting the levels of the lake to rise will be a difficult task, and one needing powerful dredging plant.

When we consider that the whole area of land in the Delta which is thoroughly reclaimed is only 2,630,000 acres, while we have 1,680,000 acres of land undergoing reclamation and producing feeble crops, or waste, or periodically flooded with salt water, and we know, moreover, that the whole of this land was once well cultivated and densely peopled, we realise what a serious calamity for Egypt was the abandonment of basin irrigation over such large areas by the Arabs and Turks. Not only did they allow 40 per cent. of the cultivated land of the Delta to fall out of cultivation, but by keeping it out of cultivation for so many years they rendered it so salted and barren that its reclamation is an exceedingly difficult problem. Whether this deterioration is due to the abandonment of basin irrigation alone, or whether it has not been intensified by other factors, is open to doubt. There is a tradition that the level of the land itself fell some 900 years ago. It is possible for the land to have fallen. The Nile, like all deltaic rivers, deposits each flood its annual layer of fresh soil. This deposit is greatest near its banks. The natural consequence is, that the river advances into the sea in a series of tongues corresponding to the different mouths of the river. There is a limit to their length in the fact that, after a time, during

some year of high flood, the river breaches its banks, and finding a shorter course to the sea, tears open a new channel and silts up the old one. This accounts for the sand-hills advancing far into the sea to the north of Beltim, at the old mouth of the Sebennytic branch of the Nile, and to the west of the present mouth. The flood water of the Nile, however, as it forces itself into the sea, meets the prevailing north-west wind, which drives back the matters held in suspension, and carrying on the sand, deposits it in long bars, stretching from mouth to mouth on a regular curve. These sand-bars are added to every year, and are considerably higher than the land behind them. In the following longitudinal section down the Delta proper, the



point C shows the position of the sand-bar with the lake behind it. The steep slope on from C is noticeable, and its tendency to slide provided the level of the sea were to fall. Since the point C is yearly added to, the Δ B C D becomes more and more liable to slide, which it might do on the occurrence of a severe earthquake appreciably lowering the sea level for a short interval of time. In case of a settlement the line B A C D E would take the position B F G D H, throwing B F out of cultivation. Some such fate seems to have overtaken Tanis or Zoan.

To-day Lake Menzaleh, with an area of 490,000 acres, rises about 60 centimetres above sea level in flood and inundates 200,000 acres of land. Lake Borillos, with an area of 180,000 acres, rises about 50 centimetres in flood and inundates 180,000 acres. Lake Edku falls below sea level in summer and rises above it in flood, with a minimum range of about 70 centimetres. Its area is 60,000 acres. Lake Abukir, with an area of 30,000 acres, had no opening to the sea. It has been dried, and is being reclaimed by an English company. Lake Mareotis, with an area of 70,000 acres, ranges between R.L. − 2·00 and − 1·50 metres referred to mean sea. At Mex, where there is a limestone bar between it and the Mediterranean, there have been erected two centrifugal pumps, of a diameter of 1·20 metre, and four of a diameter of 2·10 metres. These pumps are capable of lifting 28 cubic metres per second against a 3-metre head, and in 1896 lifted 175,000,000 cubic metres, and in 1897 they lifted 217,000,000 cubic metres at a cost of about 30*l.* per million cubic metres. Since this lake is far below sea level and has cultivated lands on its banks, it is necessary to pump up its waters and keep them from overflowing its banks, or the Government would have to pay heavy compensation. Here the action of the Govern-

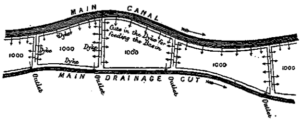
ment is quite intelligible and sound, but the same cannot be said of the ambition of those who desire to lower the levels of Lakes Borillos and Menzaleh in flood, and so save 380,000 acres from inundation when 1,300,000 acres well above the level of the lakes are still under reclamation, or waste, and when the only method hitherto proposed for reclaiming these lands is the reduction to a minimum of that very red water which alone can thoroughly reclaim them. Lake Edku differs considerably from Lakes Borillos and Menzaleh. Now that the Fazzara Canal has been abandoned no canals of any consequence tail into it, and if the drainage and escape water which finds its way into it is so limited in quantity that it can be evaporated on the area of the lake, the lake will act as an evaporating basin. If it is incapable of doing the above, the opening into the sea will have to be kept open throughout the year, at considerable expense, or the excess water will have to be pumped into the sea.

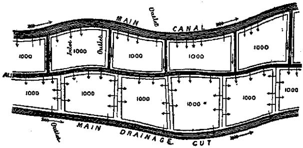
The fishing revenue obtained by the Government from Lake Menzaleh, with its 490,000 acres, is 65,000*l.* per annum, or ·14*l.* per acre. From Lake Borillos, with its 180,000 acres, the revenue is 7000*l.*, or ·04*l.* per acre. The 60,000 acres of Edku yielded 1500*l.* per annum, or ·03*l.* per acre. Mareotis, with its 70,000 acres, not in communication with the sea, yields an insignificant revenue. The large fishing revenue is due to the fact that most of the lakes are open to the sea, and it is at the openings that great part of the fish are caught. As the revenue obtained by the Government is one-third the value of the catch, the total value of fish caught is 220,000*l.* per annum.

Let us now consider what has been done to reclain the salted or swamped lands in the north of the Delta. Mehemet Ali attempted the reclamation of some of the lands by an ingenious method of colmatage or warping. The one idea in his time was the cultivation of cotton, and the reclamation of these lands was subordinated to that idea. If the land had been thoroughly reclaimed and then put under cotton by rotation for one year and warped the next, the best results might have been anticipated, for the system of warping, or modified basin irrigation, which he adopted was most ingenious. The lands were divided into basins of about 1000 acres each; they were provided with canals for filling, banks for retaining water, and drains for discharging it. The following systems were adopted :—

1. When the drainage cut was near enough to the canal to allow of one system of basins, the land was divided into a series of basins of 1000 acres each, reaching up to the drainage cut. The basins were fed direct from the canal and drained into the cut, as shown in the accompanying sketch. These basins were filled yearly, or every second or third year, according to the capacity of the drainage cut. The ordinary method adopted was to let the water run continuously over the fields, and be discharged without interruption. This succeeded very well with water taken from the Nile,

or from canals with a velocity similar to that of the Nile. Canals with a checked velocity, which had lost all the coarser particles of matter held in suspension, had to be differently treated. The water from these had to be





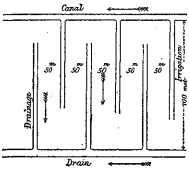
retained for fifteen days on the land and then discharged. This process had to be continued throughout the flood. By this means a deposit was obtained of all the particles held in suspension.

2. When the drainage cut was too far off to allow of only one system of basins, the following plan was adopted. The basins near the canal were fed from the canal and drained back into the canal. This presupposed a canal with a very considerable discharge. The basins which were further off were fed by "Alif" (Arabic for thousand) canals and drained direct into the cut. The basins near the canal were flooded every year, had high banks, and contained superior land. Rice followed by clover or barley, were the crops sown.

If this system had been long continued, the lands would have been thoroughly reclaimed and rendered capable of producing wheat, beans and Indian corn. But long before the land was sufficiently reclaimed to warrant cotton cultivation, the warping was abandoned and cotton cultivation begun, and in a few years the lands returned to their barren condition over nine-tenths of their area, while sickly fields of cotton continued to be cultivated in patches. In 1887 I proposed the reconstruction of some of these basins, and received 1500*l.* from the Daira Sania, to whom the land

then belonged, for that purpose. With this money I was able to begin the reclamation of 5000 acres of this land, and in three years had brought considerable areas under barley and clover, when the neighbouring villages asked the Daira to allow them to sow cotton and offered them a tempting rent. The Daira resigned the lands to cotton cultivation, and within a couple of years all traces of reclamation had vanished and the basins returned to their former waste condition.

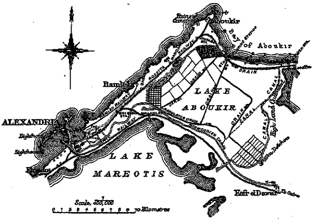
If such land has to be reclaimed by perennial irrigation, it must be thoroughly taken up, provided with numerous drains and watercourses, and have insured to it a good supply of water throughout the year. I am indebted to Mr. Frank Hazeldeen of Alexandria for the following information. He is speaking of land which had been well cultivated in the past and had to pay its full tax of 1*l.* per acre per annum, but which had deteriorated from over-saturation. He had a perennial canal on one side and a good drainage cut on the other. Such land, bought for 16*l.* per acre, and improved at an expenditure of 4*l.* per acre, brought in nothing the first year; paid its way the second year; paid 3 per cent. on the total expenditure to date the third year; 6 per cent. the fourth year; and 6 per cent. the fifth year. The Government land tax was 1·0*l.* per acre per annum, and the above profits were nett after paying the land tax and all expenses. The land to be reclaimed was divided into a number of beds by alternate canals and drains, the latter from a metre to a metre and a quarter deep, and one metre broad at bottom. The earthwork cost some ·01*l.* per cubic metre. With a good supply of water and good drainage this system ought to work well. The lands were planted with rice at first, and now cotton is being encouraged. During the winter the land is put under clover and *well washed.* It is improving in condition every year.



The following description of the reclamation works of Lake Abukir, near Alexandria, has been selected from an excellent paper by Mr. H. G. Sheppard, entitled "The reclamation of Lake Abukir," and printed in vol. ci. of the Minutes of the Proceedings of the Institute of Civil Engineers, London. Since this paper was written, the pumps which drained the lake have been taken over by the Government and removed to Mex, while the company has been permitted to drain Lake Abukir through two syphons under the Mahmudia Canal into Lake Mareotis, which lies at a much lower level.

"The area of the lake, included in the above concession, is 29,621 acres. In section it is saucer-shaped, flat in the centre, and gently rising towards the edges. The average level of the centre portion is about 1 metre below mean sea-level; and none of the land, even around the edges, is high enough to drain into the sea, which is kept out by means of a stone sea-wall. Inside of this latter is an embankment carrying the railway to Rosetta, and this practically forms the boundary of the lake for 10 kilometres on the north side.

Before the present works were taken in hand, Aboukir was merely a huge salt-evaporating basin. During summer the salt would lie in the depressions in sheets of dazzling whiteness, 3 or 4 inches thick, much resembling snowy ice in colder



regions. The salt was nearly pure chloride of sodium, and the sale of this being a Government monopoly, it was carefully guarded by a large squad of watchmen in the pay of the coastguard service, distributed round the borders of the lake.

Two ways present themselves for draining Lake Aboukir; one by raising the water by large pumps and discharging it into the sea; the other by means of syphons or culverts under the Mahmoudieh Canal, and running off the water into Lake Mareotis, the mean level of the water of which is about 1½ metre below the bed of Lake Aboukir.

The latter would naturally commend itself as the cheaper and more efficient plan; but, unfortunately, it did not meet with the approval of the Egyptian Ministry; and pumps were specified as a *sine quâ non* in the concession. There is therefore no occasion to describe the merits of the other method of drainage.*

A convenient site, then, having been found for the pumps on the line of railway to Rosetta, and within 350 metres of the sea, the pumping station was erected.

As the only fresh water available had to be conveyed in tanks by railway from Alexandria, a distance of 14 miles, it was decided to build all the foundations, both

* Subsequently the Government allowed the company to drain into Lake Mareotis by gravity, and took over the pumps for another purpose.

of engines and buildings, in cement, using salt water only. The concrete for the foundations consisted of broken pottery 6 parts, sand 3 parts and Portland cement 1 part. The broken pottery, if clean and well broken, forms an excellent substitute for stone, and is found in large quantities by excavating the ancient sites of villages or kôms. Upon the concrete the engine foundations, 9 feet 6 inches in depth, were built of brick in cement, the engine-room floor being on a level with the rails of the Rosetta line.

The engine and boiler houses were of corrugated iron. The engine and pumps, by Messrs. John and Henry Gwynne, of Hammersmith, consisted of two 'Invincible' centrifugal pumps with suction-pipes 48 inches in diameter, each worked by a separate horizontal direct-acting compound surface-condensing engine, with cylinders 17 inches, and 32 inches in diameter, and stroke of 27 inches. The circulating water was pumped by means of two independent 6-inch 'Invincible' pumps. Four Galloway boilers, 7 feet in diameter and 20 feet long, supplied steam to the engines; two only are used in daily practice. The diameter of the pump fan is 6 feet 9 inches, that of the pump casing being 15 feet 6 inches outside measurement; the latter is an excellent casting in one piece, and weighs 13 tons. Great difficulty was experienced in transporting these large castings by rail from Alexandria, as their dimensions did not allow of trains passing each other, and special precautions had to be taken to keep the lines clear. These engines were specified by the makers, each to discharge 175 cubic metres of water per minute with a lift of 3·35 metres, and a consumption of 2 kilograms of Welsh coal per actual horse-power per hour in water raised. That they were well within their contract quantity the following figures will show—

RESULT OF PUMP TRIALS, 23rd and 24th October, 1888.

—	Right-hand Engine	Left-hand Engine
Duration of trial . . . . hour	1	1
Mean boiler-pressure . . lbs. per square inch	80	90
,, vacuum . . . . . . inches	27½	27
,, revolutions per minute of engines and pump .	80	80
,, lift . . . . feet	9·10	8·87
Discharge over sill per minute . cubic metres	174·41	195·0
Density of intake water . . . . per cent.	3·9	3·9
Effective work in water raised, or W.H.P. .	110·01	119·92
Indicated H.P. . . . . . hp. cylinder	106·72	114·64
,, ... lp. ,,	91·68	82·98
Total indicated H.P.	198·40	197·54
Efficiency of pump, or $\frac{\text{W.H.P.}}{\text{I.H.P.}}$	0·55	0·60
Consumption of Cardiff coal—		
Per hour . . . . lbs.	412½	462
,, I.H.P. per hour . . . . . . ,,	2·07	2·33
,, W.H.P. ,, ... ,,	3·74	3·85
,, ,, ,, ... kilo.	1·70	1·75

In calculating the duty of the pumps, the density of the drainage water forms an important item, and is daily taken at the pumping station by a delicate hydrometer. Thus it can be easily ascertained if the water used in washing any part of the lake is being turned into the drains before it has dissolved its due proportion of salts.

The average density of the drainage water at the intake is about 1·03, but during the month of April 1888, when the lake was being first dried and the water was low in the drains, it was as much as 1·12. When the pumps are discharging 350 cubic metres per minute, this is equivalent to nearly 42 tons of soluble salts extracted from the soil per minute. Although this at first sight appears to be a very large figure, it is insignificant when compared with the total amount of soluble salts contained in the lower lands. From analysis given further on, this exceeded 10 per cent., and the weight of the soil dried being 141 lbs. per cubic foot, to effectually sweeten it to a depth of ½ metre, 466½ tons of salts had to be extracted from each acre of land constituting the bed of the lake. Such an absolute freedom from salts is, however, unnecessary for many crops, the best of soils in these parts often containing two per cent. of soluble salts. The author found that the percentage of chlorides in the water of the Mahmoudieh Canal varied from 0·146 in August and September (during flood) to 0·936 in July, when the Nile is at its lowest. During the first pumping season, and before any of the fresh-water canals were made, the boilers were supplied by tanks of fresh water brought by rail from Alexandria, the water in the intake being too salt to use with safety. The cost per month of working these pumps with day shift only is—

	£	s.	d.
Staff	45	10	0
Coal, 165–6 tons at 23*s.*	190	8	9
Stores	15	0	0
	£250	18	9

Therefore, with the pumps discharging 350 cubic metres per minute, with a lift of 9·1 feet, and coal consumption of 9·2 cwt. per hour as before, but working twelve hours per day, the cost per 1,000,000 cubic metres of water lifted is 33·1*l.*

The total cost of the pumping station was 19,962*l.*, which, under a normal lift and discharge, is equivalent to 77*l.* 6*s.* per water H.P. The need of using Portland cement in the whole of the masonry, where lime would have served equally well had fresh water been available, affected the cost considerably, as also did the custom dues levied on all the machinery imported.

The whole of the water, both for washing and for cultivation, is obtained from the Mahmoudieh Canal by means of two head-sluices, each with two openings of 1·50 metre by 1·25 metre, capable of discharging about 500 cubic feet, or say 14 cubic metres, per second, with a maximum head of 2·8 metres. The general section of the lake being saucer-shaped, as before stated, the Author determined upon two systems of canals for each half of the lake; a high-service canal running round the boundaries of the property, and a low-service canal across the centre. The two, although supplied by the same head-sluice, are separated by a regulator, which by means of loose planks sliding in a groove, regulates a difference of level amounting to about 1 metre. Water is thus supplied by gravitation to all parts of the lake, and, by a network of distributary canals, was made to

conform to varying levels. The greatest head of water held up in the main canals did not exceed 1·3 metre, the banks being 2·25 metres wide on the top, and with slopes of $1\frac{1}{2}$ to 1. As a rule, however, the slopes are only 1 to 1, both for banks and cuttings, and were found to stand well, the clay soil of the lake-bed forming an excellent puddle. Where possible the main canals were designed with a surface-slope of 7 centimetres to the kilometer $= \frac{1}{14285}$; the bed-width varied from 7 metres to 2 metres, the discharge being calculated on the basis of 30 cubic metres per acre per day; 24 cubic metres is the average quantity of water required by Egyptain crops, and 40 per cent. of this will find its way into the drains. The length of the high-service boundary canal supplying the southern half of the lake is $24\frac{1}{2}$ kilometres, that for the northern 12 kilometres. Three large main drains divided the whole lake into four parts, of about 7000 acres each; they were given a bed-slope of 5 centimetres to the kilometer $= \frac{1}{20000}$, which was all the very flat nature of the land would allow, even this necessitating a depth of cutting at the pump end of $2\frac{1}{4}$ metres. The bed-width varied from 3 metres at the head to 8 metres near the intake. *The drains are made considerably larger than theory requires, in order that they may act as a collecting basin for the pumps. These, as a rule, work only during the day, and to keep down the level of the water at the head of the drains, distant, perhaps, 15 kilometres from the pumps, it is imperative that the flow be maintained throughout the night.*

Besides the above main drains, a large drain was cut outside of the high-service boundary canals, and this extended nearly three parts round the lake, wherever there was cultivated land outside the borders. Its use was to tap all the small drains, which before Lake Aboukir was drained, discharged into that depression.

The works were carried out in 1887 and 1888.

In Egypt three systems of reclaiming salt lands are practised.

1. By 'colmatage,' or, as it is called in England, 'warping.' During the time of high Nile, water heavily charged with silt is run over the land to be reclaimed, and after this is deposited the clear liquid is drawn off and the process repeated. In course of time a sufficient depth of silt is obtained to produce a crop, the drains preventing the salts from rising and contaminating the new soil.

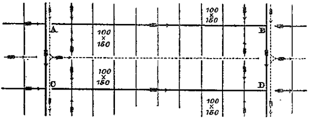
2. By washing up the salt. This is effected without the intervention of drains, and merely by passing fresh water continuously over the surface of the soil to be sweetened.

3. By washing down the salts. This is done by dividing the land into small plots by drains and dykes, the size of the plots depending upon the saltness and quality of the soil; the spoil from the drain-cuttings forms small banks round the plots, and enables them to be kept flooded constantly with fresh water. The action is thus one of forcing the salts down into the drains by mere pressure, due to the weight of water, and assisted no doubt by a process of diffusion.

The first plan can only be adopted to advantage on lands situated near the Nile, or within reach of canals having a silt-carrying velocity. The water of the Mahmoudieh Canal has deposited most of its silt before arriving at Lake Aboukir, and is useless for this purpose.

The second method of washing given is slow, extravagant in the quantity of water required, and therefore not practicable in cases where it has to be pumped off. When ordinary waste drainage water, containing, perhaps, only a trace of salt, is allowed to pass over very salt lands, the latter will be found in time to become

practically sweet, and generally covered with a thick crop of reeds, rushes, and rank grass. There are several examples of this process of natural reclamation in Lake Aboukir, at places where the drainage water from outside lands discharges into the lake. In one instance nearly 2000 acres of land had almost entirely been deprived of its salt by this means, and only required to be properly drained and irrigated to exchange its wild vegetation for useful crops of clover and barley. An attempt was made to imitate this method of washing on 6000 acres of bare salt lands on the northern side of the lake, and for this purpose it was divided into basins of about 500 acres each by heavy banks. It was proposed to keep these basins always flooded by fresh water from the boundary canal already mentioned, drawing it off from time to time, by means of the pumps, as soon as it had absorbed a due proportion of salt. This, in fact, was the original plan for reclaiming the whole of the bed of the lakes, and was only abandoned when it was found that the wave-action, due to wind over such a large surface of water, eroded and breached the banks to an extent quite out of proportion to their utility. It was also found that the water did not penetrate the stiff clay soil, and that, after the first washing or two, the water had to remain many days before it reached a density which justified the expense of pumping it off. The plan then ultimately adopted, or some modification of the same, is shown below, which represents the method of dividing up a 'hosha,' or plot, of about 70 acres area.



The land is first divided into rectangular fields, A, B, C, D, 1000 metres long by 300 metres broad. It is then ploughed up, either by steam or bullock. To minimise the effect of wind action upon the washing water, and to secure better drainage, the 'Hosha' is subdivided into twenty smaller plots, 150 metres long by 100 metres broad. With continuous changes of water, the washing out of the salt is now taken in hand, and is carried on continuously, until the soil is considered sweet enough to grow a crop of rice, or 'dineba'; the latter is a species of millet (*Panicum crus-galli*) and occurs plentifully in the rice crop. It forms a capital green fodder for cattle, and thrives on salt land much better than rice.

Before, however, any crop can be sown, it is usual to carry out the reticulation still further, and the 150-metre-by-100-metre plots are again split up into four, six, or eight parts, according to the crop to be grown. These plots are not shown in the above figure, as the work is usually executed by the cultivators themselves. Referring to it, the thick lines represent the larger drains in communication with the main drains leading to the pumps; parallel with these are the distributary canals for fresh water, shown in dotted lines. The soil from these two cuttings goes to form the

intermediate roadway, 4½ metres wide; the section through these parallels, A C or B D, is shown below. The next figure is a section through the collecting drain



A B, or C D. The small cross drains separating the 150-metre-by-100-metre plots are usually not more than 0·70 metre deep and 0·25 metre bottom width, but



they vary with the nature of the soil. The arrows represent the direction of flow of the drainage or irrigation water; the latter is distinguished from the former by being dotted.

The following analyses of the soil of Lake Aboukir, by Dr. Voelcker of London, will show that there was a most unusual quantity of chloride of sodium to be dealt with, the extraction of which would require large quantities of water applied in a systematic manner:—

ABOUKIR SOIL ANALYSIS. Dried at 212° F.

—	No. 1	No. 2	No. 3	No. 4
Oxide of iron	11·69	11·04	3·50	11·71
Iron pyrites	0·08	0·11	0·12	0·10
Alumina	6·36	10·88	4·54	11·95
Lime	2·08	7·73	29·52	8·03
Magnesia	1·79	0·93	1·10	0·50
Soda	0·79	..	0·49	0·41
Chloride of sodium	8·11	8·56	1·62	0·01
Potash	0·65	1·23	0·43	0·67
Sulphuric acid	2·23	2·56	6·16	0·14
Carbonic "	0·19	4·75	20·15	5·59
Phosphoric acid	0·16	0·19	0·35	0·38
Insoluble silicates and sand	62·23	45·81	31·51	54·27
*Organic matter	3·64	6·21	0·51	6·24
	100·00	100·00	100·00	100·00
*Containing nitrogen	0·035	0·070	0·035	0·096
= Ammonia	0·042	0·079	0·042	0·116

Samples No. 1 and No. 2 were taken from the bed of the lake, and represent the average quality of the soil over an area of, say, 25,000 acres. It consists, for the depth of a metre, of a stiff loamy clay, of 2·25 specific gravity, black in colour, and

of extreme fineness. Below this there is generally a sandy stratum of varying thickness, forming very efficient subsoil drainage; sample No. 3 is somewhat lighter, with much lime, and was taken from some of the higher land lying about 1 metre above the average level of the lake. Having been washed by many winter rains, it has nearly parted with its salt, and, in fact, has already produced a scrubby winter crop of barley planted in past years by itinerant Bedouins.

Sample No. 4 is taken from some already fully-cultivated land in the vicinity of the lake, and is for comparison only; it produces average crops of cotton, maize, and other cereals, and is worth about 5*l.* a year rental. From the above analysis it will be seen that the soil of Lake Aboukir is essentially alluvial, and formed by the deposition of Nile silt in a similar manner to all the rest of the Delta. It possesses all the ingredients of a first-class cultivable land, and only requires, by means of artificial drainage and washing, the elimination of its superabundant salts of sodium and magnesia to become so.

On examining the analysis, it will be noticed that about 50 per cent. of the soluble salts are chloride of sodium; but in an analysis, by the same chemist, of a sample of salts contained in the drainage water from the land being washed, the proportion of chloride of sodium is found to have increased to 70 per cent., magnesia and sulphate of lime being also present. This confirms, in a very marked degree, the fact well known to every agricultural chemist, that soils have the power of retaining their valuable chemical constituents whilst readily parting with those either noxious or of little importance, and there need therefore be no fear of excessive washing deteriorating the soil in any way.

To ascertain the progress of eliminating the salts from the soil, numerous and frequent experiments are made in the company's laboratory, especially arranged for the purpose.

It was found that the well-known nitrate of silver test for chlorides was the most accurate and easily managed, and was used exclusively where chlorides were concerned. It may, or it may not, be correct to assume that chlorides are the only, or the main noxious ingredient likely to be present in the soil; but, be this as it may, the broad fact remains that when the chemical tests show absence of chlorides in excess, the land invariably follows with a growth of crop in direct proportion to the decrease of chlorides.

In Dr. Voelcker's analysis, in soils taken from the bed of the lake, the chlorides amounted to 8 per cent. After one year's continuous washing this was found to have diminished on an average to about 2 per cent. at a depth of 1 foot below the surface, although in many cases, where the washing had been done under more favourable conditions, only ½ per cent. or less of chlorides was found.

With 2 per cent. of salt in the soil, a fair crop of dineba, 2 feet high, can be grown; with 1 per cent. it attains its full height of 4 feet, and sells as a standing crop at from 20*s.* to 25*s.* per acre. For 'berseem,' or clover, the percentage of salt should not exceed ½, and about the same for 'sabaini rice.'

The total amount of earthwork executed from May 1887 to September 1889 was 1,457,597 cubic metres, representing the excavation of about 72 miles of main canals and drains, some 25 miles of minor drains, and the preparation for washing and cultivating of 4140 acres. The whole work was performed by contract in the ordinary native fashion with basket and hoe. The rate paid for the larger work was

from 2 to $2\frac{1}{2}$ piastres tariff per cubic metre, say $4\frac{1}{2}d.$ per cubic yard, which included dressing the banks and keeping the works free of water.

For such work a payment of $\frac{3}{4}$ piastre per cubic metre, or 1·4*d.* per cubic yard, was the usual price paid. The total expenditure in Egypt for the whole works amounted to 77,977*l.* up to the end of September, 1889. Besides this, there was the cost of financing in London, with which the author was not concerned.

Taking the above sum, then, as the actual amount spent in the reclamation of the lake as far as it has gone, the cost per acre for the three stages of the work of reclamation will be as follows :—

	Per acre, piastres *
1. First stage. General expenses £ Eg. 72,586. Main earthworks, pumps, &c.	245·9
2. Second stage. Division into basins of 500-acre area	28·8
3. Third stage. Subdivision into small fields	76·5
4. Labour and washing for one year	27·0
5. Steam cultivation	17·0

Omitting item 2, which, as already explained, is an unsatisfactory system, the total cost of the works was at the rate of 3·664*l.* per acre exclusive of any charge for pumping drainage water. This cannot be correctly estimated, as no separate record of daily discharges of drains from lands undergoing washing treatment has been kept. The above cost, then, can only be considered as approximate, some land parting readily with its salt in a few months, while others of a heavier nature will require more than a year of continuous washing. It is the object of the Administration only to carry out as much work as will ensure the letting of the land to the fellaheen, who will not risk even their labour and seed in what might prove to be unproductive soil; it is imperative, therefore, that the Administration should cultivate to a limited extent such reclaiming crops as 'dineba,' rice and clover, in order to show the capabilities of the soil when once deprived of its salt. The cost of such cultivation, being necessarily a revenue charge, is not included in the above cost of works per feddan. Of course it will be some years before the land acquires its maximum value, and the present rental is usually, therefore, 1*l.* per acre for the first year, 2*l.* for the second, and 3*l.* for the third. These prices are readily obtainable where a crop of 'dineba' shows the land to be no longer impregnated with an excess of salt, and are sometimes exceeded where the soil has been naturally washed and drained for many years. After the third year, when the land has been worked into good condition and the country settled, it will, without doubt, let as readily at 5*l.* per acre as do similar lands in the vicinity. Villages are erected at the cost of the Administration, on suitable sites for the use of the tenants; they consist of the usual mud huts, $3\frac{1}{2}$ metres square, with dome roof, built merely of sun-dried bricks, and plastered over with clay and chopped straw; they cost about 3·50*l.* per house.

The steam cultivation is carried on with a pair of Fowler's 8 horse-power ploughing engines, using a nine-tined cultivator or grubber. Where the land is free from long reeds, the engines can work up 13 acres per day, at the cost above stated, namely, 17 piastres per acre, the consumption of coal being under 1 ton per

* 1*l.* = 100 piastres.

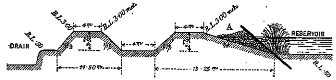
day, and costing at the site 1·50*l.* per ton. When there is much rank grass a Cuban plough is used; the natives, however, prefer the work of the cultivator as being more like their own primitive implement.

The author was engaged as resident engineer on the works, acting under the advice of Mr. James Abernethy, Past President, as consulting engineer.

The agricultural problem involved in the transforming of this barren tract into rich cultivated land, is now being worked out by Mr. V. Lang-Anderson, as manager of the estate in Egypt; and it is due to his kind assistance that the author was able to collect much of the information contained in the above notes."

It has been already remarked that for reclamation by perennial irrigation it is necessary to have one's water supply ensured throughout the year, and efficient drainage. It is frequently very difficult to obtain water in summer, and, as reclamation extends the problem becomes more difficult every day. I see no reason why the supplies needed in summer should not be stored on the lands to be reclaimed. I take as an example the little Borillos, a depression containing 90,000 acres, lying about ·50 metre above mean sea, and separated from the great Borillos by a dyke constructed in 1887. I would divide this area into three basins of 30,000 acres each, and surround one of them by double banks of the following section.

An area of 30,000 acres covers 12 kilometres by 10·5 kilometres, and the dyke would therefore be 45 kilometres long, with a cubic content of 1,960,000 cubic metres, costing 39,200*l.* as an outside figure, because the area is intersected with old banks, which might be utilised. During flood the water would be allowed to sweep over the area and wash it, while in



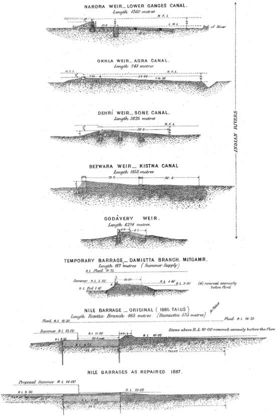
winter the canals would be tailed into this basin and fill it by the end of April, up to which date there would never be any lack of water. Early in May, rice sowing would begin and the water supply would fail everywhere; the reservoir could then be drawn on for water; and since it had been filled to a depth of 1·50 metre, of which ·75 metre might be considered as lost, the remaining ·75 metre would represent (126,000,000 × ·75) = 94,500,000 cubic metres, or a discharge of 945,000 cubic metres per twenty-four hours for 100 days. This would suffice for $\left(\frac{945,000}{40} = \right)$ 23,600 acres of summer rice. This summer rice would be worth 70,000*l.* The land

cultivated with summer rice would be gradually reclaimed, while the land in the basin itself would become, in the course of seven or eight years, valuable land. One of the other belts might then be turned into a reservoir, and this one planted with cotton.

The borrow pits, from which the earth for the banks was taken, would constitute a good drainage cut, and convey the drainage water to the dyke near the great Borillos, where it would flow freely into the lake, through an opening provided with a self-acting shutter. If dry crops were taken up, and a thorough reclamation of the land attempted, a pumping station lifting about 1,000,000 cubic metres per day about 2·5 metres in height, for four months per annum, would turn this tract into first-class land. The wash of the waves on the dykes would be guarded against by a growth of bulrushes and "birrîya" weeds; the staking of the dykes would cost 50*l.* a kilometre, or 2250*l.* altogether. If these were not sufficient, masonry revetments would be necessary for the dykes on the south and east sides of the lakes, as the force of the north-west winds is always felt there. Such revetments would be similar to those in the more important basins of Upper Egypt, and would cost 400*l.* per kilometre of dyke.

In Chapter XII. will be found descriptions of the most successful land reclamations in the valley of the Po. Italian experience has fixed upon 60 centimetres as the minimum level at which subsoil water should be permanently maintained below ground level if healthy crops are to be produced. To ensure this on lands which are drained by *pumping* it is essential that the drains should be perpetually running, and with this object a small pump should be always erected near the main pump on the main drain so that the water in the drains should never cease flowing, but be always in movement whatever its quantity. If the water is allowed to cease flowing and to collect in the drains and a pump is set to work, it will be found that the drain near the pump will become dry, and at a distance from the pump the water will not even have begun flowing. On this point see the remarks in italics on page 248 in Mr. Sheppard's Report, and also the observations in Chapter XII., on the reclamation works in the valley of the Po.

SECTIONS OF WEIRS.



CHAPTER IX.

THE BARRAGES.

Barrages or weirs—Their object—Temporary Barrages on the Nile—The Nile Barrages—Description—History of the Barrages—Detailed description—Method of working previous to 1884—Principles of working adopted in 1884—1884 to 1886—Repairs begun in 1887 under Colonel Western—Original method of construction—Method of repairing—Details of closing springs—Principles involved in method of repairs adopted—Mr. Reid's reports for 1887, 1888, 1889, 1890—Error in canal regulation on the completion of the Barrages—Mr. Foster's repairs in 1891—Stock ramming in 1896—Grouting in 1897—Subsidiary weirs under construction.

IT will readily be understood that a perennial canal taking its supply from a river is far more effective if a weir or barrage is thrown across the river just below the canal head. The barrage arrests the flow of the river, raises the water surface, and so enables the river to feed the canal at a much higher level than would otherwise be possible. The advantages are twofold: (1) The canal in summer is not dependent for its discharge on the level of water in the river, for however much the level may fall on the downstream side of the barrage, the level on the upstream side can be maintained at the height for which the work was designed, so long as the supply of water in the river is equal to the discharging capacity of the canal. And if, owing to lack of water in the river, this level cannot be maintained at its full height, it can be maintained higher than what it would be if there were no barrage. Indeed, under these conditions the canal can take the full supply of the river and allow none to pass the barrage. (2) The bed of the canal taking off from above the barrage can be considerably raised, and great economies made in the construction and maintenance of the canal itself. For suppose that the full summer supply in a canal is 3 metres and the minimum depth of water in the river 2 metres, without a barrage it would be necessary to make the bed of the canal 1 metre below the bed of the river. Now if a barrage is constructed which can hold up 4 metres of water, and if even the river downstream of the barrage dries up, still the upstream water surface will be 4 metres above the river bed, and the bed of the canal may be made 1 metre above the bed of the river and the canal will still have 3 metres depth of water in time of low supply.

Both temporary and permanent barrages are employed in Egypt. Temporary barrages are of two kinds. If the work is meant to raise the level of the water and allow a certain quantity to pass down the river, the material

employed is rubble stone. If the work is meant to hermetically seal the river at its tail and make a barrier between the sea water on one side and fresh water on the other, the material employed is earth protected by sand-bags and stakes. The temporary stone barrages are made of rubble pitching carefully tipped from boats into the river. The whole length and breadth of the platform is covered with about 1 metre of tipped stone, then the next layer of 50 centimetres is laid, and so on; this is done to avoid undue scour at any one spot. These barrages need very careful protection at the two flanks to secure them from the back action of the water. Frequent soundings are taken on the downstream side, in order to find out if any displacement of the stone is taking place. When the main platform is brought to a height of 50 centimetres below summer level of the river, a small bank of stone 2 metres wide at top, 6 metres at bottom and 2 metres high is placed on the upstream edge of the platform (see plate XXI.), being gradually raised in 50-centimetre layers. The temporary barrage shown in the plate has a platform 18 metres wide at top, 26 metres at bottom, and 3·5 metres high. If the supply of the river falls and leakage has to be stopped, coarse metalling is thrown on the upstream side, then finer metalling, and if no water at all is to pass the dam, earth is eventually thrown upstream of the metalling and the dam made water-tight. On the rise of the river the crest or bank is removed, and the floods pass over the platform without any perceptible afflux. On the Damietta branch of the Nile such dams have been put in on a length of 160 metres, damming the low-water channel of the branch. They have held up 1·50 metre in low Nile with a maximum discharge of 75 cubic metres per second passing over them. On one occasion, when the Nile supply was very deficient, the dam was made water-tight and held up 3·20 metres. In constructing these temporary dams on the Nile, the greatest head of water should be such that the maximum water pressure bears to the submerged weight of the rubble a proportion of 1 to 40 or 50.

Such dams on the Damietta branch need 10,000 cubic metres of stone, and cost as a first charge 5000*l.* The platform, howerer, becomes cemented with mud, and is to all practical purposes a permanent work. The yearly removal before the flood of the stone crest, and its renewal at the beginning of the summer, is a trifling and insignificant work.

The temporary earthen dams on the Damietta branch cost 4000*l.*, and on the Rosetta branch 8000*l.* Here the whole work is swept away by the flood and has to be renewed when needed.

The permanent Barrages at the heads of the Rosetta and Damietta branches of the Nile are open dams, provided with openings along their entire length. Since the Nile in Egypt, during flood, is considerably above the level of the country, which is protected by dykes from inundation, it would have been dangerous to build a solid barrage which would

have still further raised the water surface, unless a length of barrage could have been obtained much in excess of the normal width of the river. Plate XXI. gives cross sections of the more important barrages in India (taken from the Roorkee Treatise of Civil Engineering) and of the Nile Barrages. It will be seen that most of the Indian barrages are solid ones. An afflux of 3 metres in summer corresponds to about 60 centimetres in flood on some of the Indian barrages.

As early as the beginning of this century, Napoleon had spoken of the necessity of some regulation at the bifurcation of the Nile, in order to send the whole supply of the Nile first down one branch and then down the other, and thus double the inundation in flood: "Un jour viendra où l'on entreprendra un travail d'établissement de digues barrant les Branches de Damietta et de Rosetta au ventre de la bache [the bifurcation], ce qui, moyennant de batardeaux, permettra de laisser passer successivement toutes les eaux du Nil dans une branche ou dans l'autre, et de doubler ainsi l'inondation."

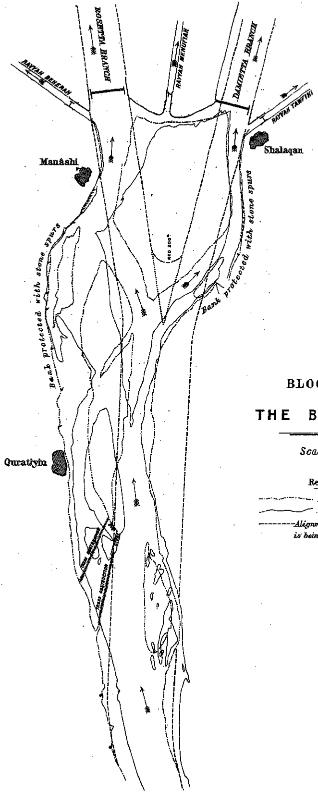
In 1833 Mehemet Ali Pasha, Viceroy of Egypt, finding it exceedingly difficult to clear the new summer canals sufficiently deep every year to receive the low level summer supply of the Nile, began closing the head of the Rosetta branch with an enormous stone dam in order to send the whole supply down the Damietta branch, which branch used to feed all the important canals. Linant Pasha induced the Viceroy to stop this rash proceeding, and proposed the construction of two barrages about 10 kilometres below the bifurcation, one on either branch. He proposed to build the barrages in the dry, and turn the Nile through them, closing the original channels with earthen embankments, opposite the new diversions. Mehemet Ali approved of the plan, and ordered the Pyramids to be dismantled and the stone removed to the Barrages. When they proceeded to consider the method of demolition and transport, Linant Pasha proved to the satisfaction of the Viceroy that owing to the building of the Pyramid from the bottom upwards, it would be necessary to dismantle it from the top downwards, and consequently more costly than the opening of new limestone quarries on the bank of the Nile near Cairo; the Viceroy gave up the idea. The excavation of the foundations was well advanced, the workshops built, and the collection of materials in hand, when Mehemet Ali changed his mind and stopped the works. With the aid of the corvée he dug the main summer canals deep enough to dispense with the barrages, and for seven years, from 1835 to 1842, no more was heard of the latter. In 1842 Mougel Bey arrived in Egypt, and recommended the present Barrages and fortifications at the bifurcation itself. The idea of fortifications apparently pleased Mehemet Ali's military mind; he conceived the idea of making the bifurcation the military capital of Egypt, and the works were immediately sanctioned and begun. Mehemet Ali

died in 1848. By 1853 the works had not advanced sufficiently to please Abbas Pasha, the Viceroy, who dismissed Mougel Bey, and ordered a new man, Mazhar Bey, to finish the works on Mougel Bey's plans. The works were completed in 1861 at a cost of 1,880,000*l.* exclusive of the corvée. The Barrages, fortifications, canal heads, &c., are considered as having cost the country 4,000,000*l.* Commissions of inquiry sat on the Barrages in 1863, 1865 and 1867; their conclusions are embodied in Linant Pasha's memoirs. In 1863 they closed the Rosetta Barrage for the first time, but reopened it almost immediately afterwards owing to a settlement of part of the work. Later on, the method of repairing this settlement will be described, as well as the further history of the work.

Plate XXII. gives a block plan of *the* Barrages, while Plate XXIII. gives longitudinal and cross sections of the Rosetta branch Barrage. It will be seen that the Barrages are open dams across the heads of the Rosetta and Damietta branches of the river at the apex of the Delta proper. Of the two branches, the Rosetta has one-and-a-half times the flood supply of the other, while its bed is some 2 metres lower. The Rosetta Barrage is 465 metres between the flanks, and the Damietta one 535 metres. These Barrages are separated by a revetment wall 1000 metres in length, in the middle of which is situated the head of the Rayah Menoufia, or "Menoufia feeder," which feeds all the canals in the provinces of Menoufia and Garbieh. The Rayah Behêra, intended for the irrigation of the province of Behêra, has its head situated on the left bank of the Rosetta branch just upstream of the Barrage. The new Rayah Tewfiki, intended for the irrigation of Sharkia and Dakalia provinces, has its head on the right bank of the Damietta branch, just upstream of the Barrage. These canals are intended to accomplish the whole summer irrigation of Lower Egypt, once the Barrages are repaired. Before the repairs (to be shortly mentioned) were executed between 1887 and 1890, the Barrages would have been thus described :—

"The platform * of the Rosetta Barrage is flush with the river bed, being 8·90 metres above mean sea, or 8·30 metres on the Barrage gauge. Its width is 46 metres, and thickness 3·5 metres. It is composed of concrete overlaid by brick and stonework. Plate XXIV. gives sections of this work on an enlarged scale. Downstream of the platform was a talus of rubble pitching varying in places from 16 metres to 3 metres in depth, while its width was between 2 metres and 50 metres. The left half of the platform is laid on loose sand, the right half on a barrier of rubble pitching overlying the sand. This loose stone barrier is 10 metres high and 60 metres broad at the deepest part, and tapers off to zero at the ends. It closes the original deep channel of the river, and its only cementing material is the slime deposit of the Nile. This deposit has to all appearances made the

* Taken almost verbatim from the minutes of the 'Proceedings of the Institution of Civil Engineers,' vol. lxxxviii. part ii. Wherever the texts differ the error is in the 'Proceedings Inst. C.E.'



BLOCK PLAN
OF
THE BARRAGES

Scale $\frac{1}{40,000}$

Reference

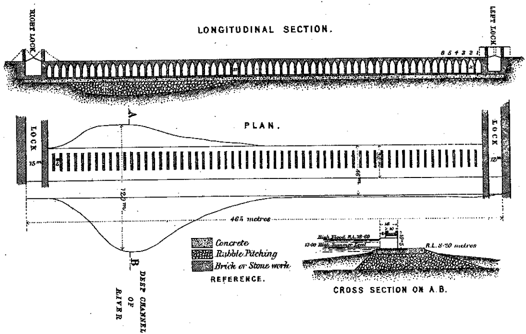
.... 1897

.... 1887

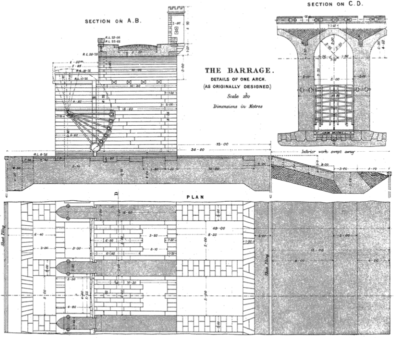
--------*Alignment of the Nile which is being worked for.*

ROSETTA BRANCH BARRAGE.

JANUARY 1884.



Scale $\frac{1}{3,000}$


SECTION ON A.B.
SECTION ON C.D.
THE BARRAGE.
DETAILS OF ONE ARCH.
(AS ORIGINALLY DESIGNED.)
Dimensions in Metres
Inferior work swept away
PLAN
Sheet Piling
A
B
D
C

platform water-tight. The platform supports a regulating bridge with a lock at either end. The bridge consists of 61 openings, each 5 metres wide; the lock on the left flank is 12 metres wide, while that on the right is 15 metres. Fifty-seven of the piers are 2 metres wide, while three of them are 3·50 metres wide each. Their height is 9·75 metres. The lock-walls are 3 and 4·75 metres wide respectively. The piers support arches carrying a roadway. The two locks are provided with drawbridges. The concrete of the platform is inferior, while Mougel Bey condemns that under the ten openings from No. 5 to No. 14. The floor here settled some 10 centimetres during the floods of 1867, producing a deflection in the superstructure both horizontally and vertically. These ten openings were enclosed within a cofferdam 5 metres high and 2 metres wide, composed of a wooden framework, filled with stiff clay, overlaid by stone, resting on the platform. Of the 61 openings, some are worked by means of the original iron gates 5 metres broad and 5·5 metres high, shaped like the arc of a circle, and supported at either end by iron rods radiating from the arc to the centre; here they are attached to massive iron collars working round cast-iron pivots embedded in the masonry of the piers at the centres of the arcs. Plate XXIV. gives details of these gates. It was originally intended to lower the gates by their own weight, and to raise them by pumping air into the hollow ribs, but the principle did not work. In their place powerful crabs, travelling on rails at the roadway level, raise and lower the gates by means of chains attached to the bottoms of the gates. The openings unprovided with iron gates are closed by movable wooden verticals resting against horizontal iron girders fixed to a wooden frame within the grooves. The iron gates and wooden piles, when lowered, do not reach the platform of the Barrage; they rest on iron gratings 30 centimetres high, fixed into the piers just above the platform, *vide* Plate XXIV. These gratings allow of a free passage of the water when the gates are down. They were originally put in to prevent deposits of mud in front of the gates when shut.

The Damietta Barrage has ten openings more than the Rosetta Barrage, or seventy-one openings altogether. The platforms and superstructure are on the same level and exactly similar. No record exists of the state of foundations, but Mougel Bey states that the work here is excellent, since it was practically built in the dry. This Barrage was supplied with horizontals in 1884, and used for the first time; since the 15-metre lock was unprovided with gates, it was necessary to close it by a cofferdam."

Previous to 1884 the Barrages were regulated in the following manner: When the Nile gauge stood at 12·50 metres, which generally happened in March, the Rosetta Barrage gates and piles were quickly lowered to their full extent, beginning at opening No. 1 and closing at No. 61. The consequence was a rapid current through the last openings just before they were closed. It was on one of these occasions that the ten openings from No. 5 to No. 14 were injured, according to the Report of the Egyptian foreman on the work. The Government Report states that they were injured during the floods of 1867 owing to contracted waterway. As soon as the gates and piles reached the gratings they could descend no further and the work of regulation was at an end for that year. The upstream

gauge rose to 13 metres, while the downstream gauge fell to 11·25 metres; so that, with a difference in water surface of 1·75 metre, there was a gain in water level of only ·50 metre. This was due to the fact that the Damietta Barrage was open. Of the water which escaped through the Rosetta Barrage, practically the whole found its way through the iron gratings. These gratings with a head of 1·75 metre, were capable of discharging 240 cubic metres per second. The river kept falling through April, May and June, and during the whole of this time the Damietta Barrage was open, as well as the gratings of the Rosetta Barrage. There was not sufficient water in the Nile to allow of a head of 1·75 metre on the latter, and it fell to 1 metre. Towards the end of June the up and down stream gauges roughly indicated 12 metres and 11 metres respectively. If the Rosetta Barrage had failed in June, the loss of head in the Delta canals would have been ·35 metre. When the Nile began to rise in July, and the upstream guage read 13 metres, the gates were raised as quickly as possible, the river fell to 12·50 metres, and was allowed to recover as the flood rose. This it did generally in six or eight days.

After an inspection of the Barrages in January 1884, and a comparison of previous gauges, it was determined to maintain above the Barrages a constant gauge of 13 metres. This resolve was supported by the following considerations.

The studies of Mr. (now Sir John) Fowler, Past-President Inst. C.E., had proved that the brickwork on the surface of the platform was good, however inferior the concrete substructure might be.

The severe action below the Barrage when a gate was lowered to its full extent was found to be due to iron gratings or "windows" in the foundation, and not, as it had been supposed, to a honeycombed foundation. This fact was apparently unknown to many of the writers of the reports on the Barrages. Indeed, it ought to have been evident that if all that action was due to fissures in the foundations, the Barrage would have been swept away years ago.

The Okhla dam at Delhi, on the river Jumna, a mass of loose rubble stone with absolutely no foundation, holds up yearly 3 metres of water, when the water pressure per lineal foot bears to the weight of the dam a proportion of $\frac{3125}{129600}$, or $\frac{1}{40}$. Nile sand is much finer than that in the Jumna, and will therefore require a lower coefficient; but this is a difference of degree and not of kind.

Considering the Barrage a thoroughly unsound work, and relying only on friction, it was determined to make the submerged weight of masonry bear a ratio of 50 to the pressure of the water going to be brought on it. Springs might cause a slight subsidence of any part of the Barrage, but it could not be moved as a whole. The pressure of a head of 3 metres of water would be 4500 kilogrammes per lineal metre. The submerged weight

of the platform was 150,000 kilogrammes per lineal metre. The coefficient between them was $\frac{1}{33}$. That this proportion might be $\frac{1}{50}$ it was necessary to make the rubble talus everywhere 40 metres wide and 3 metres deep, with a submerged weight per lineal metre of 75,000 kilogrammes. This made the submerged platform and talus together 225,000 kilogrammes as compared to the pressure of 4500 kilogrammes. Since only one-third of the talus was completed in 1884, the barrage was not required to hold up more than 2·2 metres of water; on the completion of the talus in 1885 3 metres of water were held up.

About the end of January 1884 the river gauge fell to 13 metres. From this date the gates and piles were gradually lowered in the Rosetta Barrage, so as to maintain this gauge. When the gates reached the

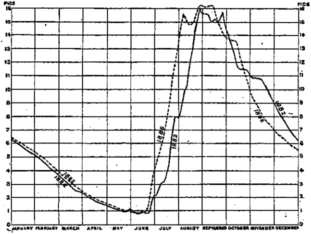


FIG. (1).—ASSUÂN GAUGE (Southern Boundary of Upper Egypt).

Scale 1 pic = 54·04 centimetres.

gratings and the piles were driven home, the work of closing the gratings was taken in hand, while the talus was strengthened with 20,000 cubic metres of rubble pitching. Owing to the incomplete state of the talus, no more than 2·2 metres of water were held up on the Barrage. Attention was now directed to the Damietta Barrage, which was strengthened with 12,000 cubic metres of rubble pitching; the left flank lock was closed with a stone dam, the right lock was repaired and opened for navigation, and a channel for boats dredged to and from it; and all the openings were provided with oak horizontals and sheet-piles, and gradually closed. At this juncture Nubar Pasha, at Sir Colin Moncrieff's request, gave a special grant of 18,000*l.* over and above the ordinary Budget, and so enabled the

work to proceed without interruption. Eventually, at the end of the season, the Rosetta Barrage held up 2·2 metres and the Damietta 1 metre, while the water surface above the Barrages was 13 metres instead of 12 metres, as it would have been under the ordinary method of working. On the 7th of July the Nile began to rise, on the 13th of July the Damietta Barrage was opened, and the Rosetta between the 18th and 31st.

The Nile at Assuân during the summer of 1885 was lower than it had been in 1884, and almost similar to what it was in 1882.

The Nile curves at Assuân (Fig. 1) for 1882 and 1885, and also at the Barrage (Fig. 2) have been plotted for comparison. It will be seen that the water surface above the Barrages in 1885 was 1·20 metre higher than what it was in 1882. During 1882 a discharge of 50 cubic metres per

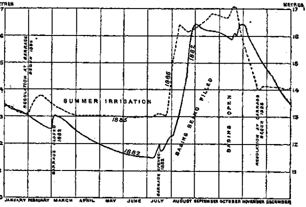


FIG. (2).—BARRAGE GAUGE. UPSTREAM.

Zero of Barrage Gauge 60 centimetres above mean sea.

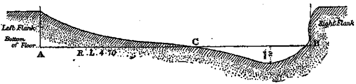
second entered the Rayah Menoufia; during 1885 there was a uniform dis charge of 120 cubic metres per second. This year the talus was completed with 34,000 cubic metres of rubble pitching, and a small temporary stone dam was raised on it, with its crest at reduced level 11·50 metres, so that the Barrage might hold up 1·5 metre, and the stone dam 1·5 metre, or 3 metres of water between them, the pressure being distributed. This dam was removed before the flood, and the materials were added to the talus. The wooden horizontals were found untrustworthy in both Barrages, and rolled iron beams were substituted. The cofferdam round the ten weak openings was considerably strengthened. Eventually the Rosetta Barrage held up 3 metres and the Damietta Barrage 1·6 metre of water. The Nile began to rise on the 5th July, and the Barrages were completely opened by the 24th.

During 1886 Mr. Perry, who had been resident engineer under me in 1884 and 1885, was put in charge of the Barrages, and worked on the same lines as in 1885, with the same results.

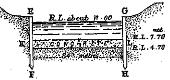
In 1887 Sir Colin Scott-Moncrieff put the Barrages under Colonel Western, C.M.G., and Mr. A. Reid, C.M.G., of the construction branch of the irrigation department, and the repairs, to be described further on, were begun.

It will be interesting to record the method in which the Barrage was constructed. The following particulars were given to me by Mougel Bey himself:

A level of 8·80 metres above the Mediterranean Sea (or 8·20 metres on the Barrage gauge) was fixed as the mean bed of the river at the bifurcation. The floor was to be 3·50 metres deep, and consequently a reduced level of 4·70 metres was the formation level of the bottom of the floor. Owing to the scour along the right bank of the Rosetta branch, the bed of the river was some 10 metres below this level at the deepest points; while on the left bank there was a considerable silt deposit above it.

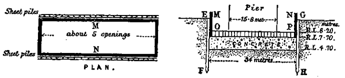


The above represents a cross section of the Rosetta branch, at the site of the Barrage during construction, and the line A B the bottom of the floor: the part from A to C—where the floor is below the bed of the river—was first constructed. The sand was excavated as far as possible in the dry, and then two rows of sheet piling were driven down along the up and down stream faces of the platform.

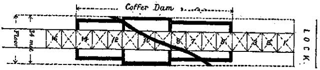


In the above cross section E F and G H are sheet piles within the sheet piling; the sand was dredged out down to R.L. of 4·70 metres, and concrete skipped into the water, to its full thickness of 3 metres, and then allowed to set. Next season the sand was removed from above the concrete K L, and a cofferdam M N was erected on the concrete, enclosing the space to be occupied by about five openings. The cofferdam was filled with stiff clay, made water-tight, and the water was pumped out. The springs through the concrete were then staunched, the stone and brickwork

floor O P laid over the concrete, and the piers raised to 1 metre above water level. The cofferdam was then moved forward, and the space to be occupied by five new openings enclosed and treated in the same way. The sheet piling E F and G H was not cut down to floor level, but projected both up and down stream of the platform to a height of 1 metre above the floor. There seems to have been no difficulty experienced in this method of working, except under the arches numbered 7, 8, 9 and 10, near the left flank; here the sand was of a particularly fine quality, dark in colour, and very light, with the springs strongly impregnated with decayed organic



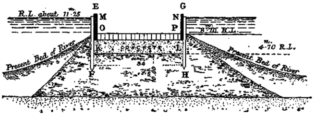
matter. In spite of the dredger working in still water, the fine sand poured in fast from between the piles, and after being dredged was allowed to accumulate to a height of 8 metres and upwards, just outside the sheet piles. The more it accumulated the more the silt ran in, until the deepening of the trench became an impossibility. Mougel Bey wanted to postpone the work to the following year, but the Viceroy was urgent: men were crowded into the quicksand, the concrete skipped in, and the mixture of concrete and quicksand had to do duty for the floor. Mougel Bey says that the concrete there could not be more than 1·50 metre thick; Linant Pasha says that the springs here were always considerable, cracks appeared in the



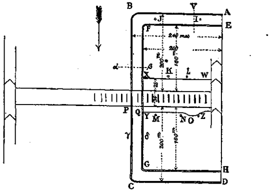
Barrages before any water was held up on the Barrage, and eventually this part of the Barrage failed and was surrounded by a cofferdam.

Referring to the cross section of the river on page 263, it will be seen that the construction of the Barrage along the part C B, where the floor lies higher than the bed of the river, could not have been carried out as above. Here a mass of loose stone was pitched into the river from boats, until the upper surface of the tipped stone corresponded with the bottom of the platform, or the line A B. Into this barrier of stone, sheet piling (along the up and down stream edges of the platform) was driven in as far as it could go. Sail cloth was laid on the upstream side of the piles, and held

against the piles by the force of the current. The concrete was skipped into the water between the piles. Theoretically the tipped stone was at the R.L. 4·70, but, practically, it must have been much lower, to allow of the extra concrete being skipped in here. As much of this concrete was skipped into running water, great part of the lime was washed away, according to Linant Pasha. Subsequently, when the cofferdam was erected



on the concrete for the completion of the floor and superstructure, the springs in places were so excessive that the floor level had to be raised 50 centimetres above the general level. The concrete was composed of broken stone, pure lime and artificial puzzuolana in the ordinary proportions. No exact record exists of the proportions, as far as I have been

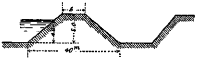


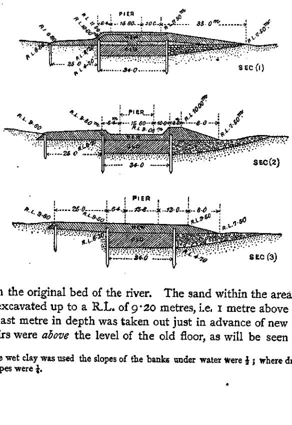
able to ascertain. Much of this concrete has not set, and in places has been found like pudding, though in others it is as hard as rock.

The Barrage repairs were begun in 1887 and completed in 1890.

A beginning was made with the left half of the Rosetta branch Barrage, which contained the injured openings. Two earthen dams, A, B, C, D, and E, F, G, H, were made round the left half of the Barrage, as shown in the accompanying sketch.

Pumping stations at I and J kept the water at a low level between the banks, and so relieved the springs in the work. X, Y, Z, W, is the area within which the repairs were executed, and K, L, M, N, O, were 10 and 12 horse-power portable engines, working centrifugal pumps which kept the foundations and work dry. The water from the pumps was carried in wooden troughs supported on trestles, which troughs threw it into the Nile, outside the banks. At α and β the deepest water was found, and the shallowest at γ and δ; the former section is represented in the figure. Sandbags,* costing 1000*l.*, were used in the construction of the earthen bank, which work was much facilitated by the closing of the Barrage gates throwing back water on the bank. At P and Q, where the dams were to pass over the pitching on the downstream side of the Barrage, channels were dredged through the pitching to allow the clay bank



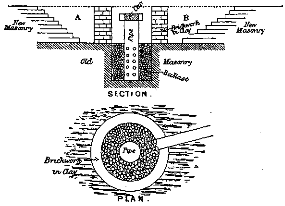


to rest on the original bed of the river. The sand within the area X, Y, Z, W, was excavated up to a R.L. of 9·20 metres, i.e. 1 metre above the floor, and the last metre in depth was taken out just in advance of new masonry. All repairs were *above* the level of the old floor, as will be seen from the

* Where wet clay was used the slopes of the banks under water were ⅓; where dry earth was used the slopes were ½.

three sections given on page 266. An upstream apron, 25 metres wide and 1·25 metre deep, of masonry was added to the Barrage; while the floor under the arches and on the downstream side was repaired according to its state and requirements, each opening being taken on its own merits.

In the three preceding sections the first is a section through arch No. 9, the worst of the series; the new work in this arch, and in number 10, was taken down to the old floor on a width of 1 metre only; up and down stream of this metre belt, the new work was laid on the sand which overlay the old work to a depth of some 50 centimetres. The springs here were very bad, and there were fears of the arches collapsing. The second and third sections are through ordinary openings. (It was a fatal mistake for the original sheet piling to have been left projecting about one metre above the floor. The water issuing through the openings shook the piles, disturbed the bed near them, and caused very violent springs along the sheet piling.) The springs under the arches near the settled work threw sand, and were not exposed, as explained above in the description of section No. 1; along the sheet piling the springs threw clear water.

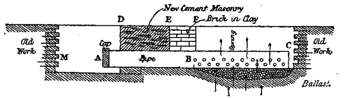


The springs were closed in various ways, and two of the methods are given here in detail. If a spring burst out outside the old work, it was immediately covered with ballast, and in finding its way through the ballast, in time ran quite clear. Springs along the sheet piling were closed either by vertical pipes or by horizontal ones.

1. (Vertical Pipes).—The spring was dug out to a depth of say 30 centimetres below the surface of the old masonry; and a vertical tube of from 5 to 10 or 15 centimetres diameter, according to the quantity of the water, was inserted. The hole was then filled up with ballast round the

tube. This tube was drilled with holes on the lower half of its length, while at the upper end were cut the threads of a screw, so that a cap might eventually be screwed on. Round the pipe, and removed about 10 centimetres from it, a ring of brickwork in stiff clay was built, open on one side; the cement masonry was then brought up from A and B till it was flush with the brickwork in stiff clay, and was allowed time to set. When set, the brickwork in clay was removed, and the space between the pipe and the cement masonry was filled up with cement mortar, or concrete or brickwork, an open space being still left on one side to allow the water coming up through the ballast to flow freely away. When the cement mortar had thoroughly set, and was strong enough to prevent springs working up through it, the opening was quickly shut up with dry cement and cement mortar, and weighed down, and the water began to flow freely through the top of the pipe. When the cement closing the opening had thoroughly set, the cap was screwed on the pipe and the whole built over.

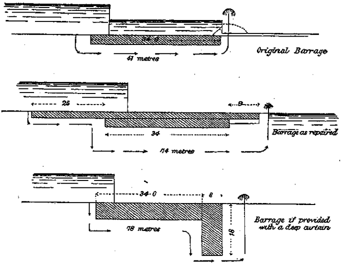
2. (Horizontal Pipes).—The pipe in this case was drilled with holes on half the circumference of half the length, i.e. on a quarter of its surface, and was laid horizontally in a trench, with the holes over the spring, which had already had ballast strewn over it. The ballast was spread round half the pipe to the axis B C. At E F a ring of brick in stiff clay was built round the pipe, and at D E cement masonry round the pipe. When the masonry at D E had set thoroughly, the brickwork in clay was removed and replaced by cement mortar or brickwork, while the space from B to C was covered with cement mortar and masonry, and the water allowed to flow down the pipe C B A. Great care had to be taken that a hand-pump kept the water at M always lower than the top of the pipe, until the masonry above B C had thoroughly set. When the masonry had set the cap A was



screwed on, and the whole space carefully built over in cement masonry. This system would be handy in a lock-gate recess. There were other methods of treating springs if they ran through a clearly defined orifice, such as putting in a small bag full of dry linseed and letting it swell, and closing the spring, which could then be plastered over; or by cutting off the bottom of a bottle, putting it over a small spring, building round

(taking care always to leave an opening till the cement had set), and eventually corking the bottle; but the two methods given in detail never disappointed, and can be strongly recommended. No attempt was made to force liquid cement down the pipes.

It will be noticed in the cross sections of the repaired Barrage floor given on page 266 that the floor has been raised and lengthened, while no deep curtain wall has been provided. Sir John Fowler's borings near the Barrage had disclosed that the nature of the subsoil did not improve as one went deeper, and therefore nothing more was to be gained by a deep



curtain wall beyond what could be gained by a horizontal extension of the floor. It was feared also that a deep curtain wall, taken down far below the bottom of the existing platform, might endanger the platform by disturbing the sand lying under it. By an extension of the floor, both up and down stream, the points at which water enters the strata under the Barrage floor from the upstream side, and issues as springs on the downstream side, have been placed so far apart, that the resistance the water will meet with on this length will be sufficient to deprive it of the force necessary to move sand, and carry it away from under the work. The springs will issue clear, and be harmless. The above figures explain the action of the springs and the distance they have to travel:—

The following four reports give the official descriptions of the four seasons' working. The first three were written by Mr. Reid, and the last

by Mr. Lieurmer, who took over the work when the repairs were completed. The lucidity of Mr. Reid's Report has kept pace with the excellence of his work. The directing spirit of the whole was Colonel Western, R.E., C.M.G.

"*Barrage repairs*, 1887.—It having been decided to commence the work of repairing the Barrage by strengthening the floor of the left half of the Rosetta Bridge, the enclosure of that part of the structure within earthen dams was begun on December 2, 1886. The dams were double, the outer dam having been intended to act in the case of the inner one slipping. As the orders of the Public Works Ministry were to the effect that the water surface of the Barrage should be maintained at R.L. 13·00, if possible, and should never, except under pressure of threatened accident, fall below R.L. 12·80, the crests of these upstream dams were kept to a uniform level of 14·50. They were constructed in water varying in depth from 1½ metre near the shore to 5 metres in the middle of the river.

The downstream dams were brought to the level of 12·50 as the surface of the water was at R.L. 12·00 when they were made, and fell steadily to its summer level of 10 in April.

The dams were constructed in two months without any difficulty. The gates of the left half of the Barrage having been shut so as to reduce the flow of the water over the area to be enclosed, the two banks upstream and parallel to the Barrage were run forward for about 8 metres, by end-tipping, Bowles Portable Railway and Rolling Stock being used. At this point the current, setting diagonally towards the open half of the Barrage, and the draw caused by the leakage through the shutting of the closed half, prevented further progress being made in this manner. The completion of the outer dam was then pushed forward. At the end of the completed portion of the dam, a boat bridge 40 metres long was got into place, and a similar bridge was made 20 metres from the point at which the dam changed its direction and turned to meet the Barrage. These two bridges were finished with a plank roadway 12 metres wide, and the bed of the river below them, and for 20 metres downstream was floored with sand bags to prevent deepening by scour. The portions of the dam between the ends of the two boat bridges, and between the outer bridge and the Barrage, were brought to water surface by dropping sand bags along the alignment of its inner edge and backing with earth tipped from boats.

When the dams were so far completed, there remained only the gaps crossed by the boat bridges. These were 40 metres long and 1½ metre deep, the current through them running about 1 metre per second. These gaps were closed by dropping sand bags off the bridges, care being taken to raise the bottom of the gap uniformly, so as to have always a wide shallow stream in preference to a deep narrow shoot of water.

As the bottoms of the gaps were raised, the water inside the dam fell until there was a difference of level between upstream and downstream of 5 metres. The bags were then tied together in bundles of from 20 to 3, and the gap closed. In all 41,000 bags, each holding 0·14 cubic metre, were used. They were ordinary grain bags, and when filled with earth were closed by sewing with twine.

Whilst the construction of the upstream dams was in progress, two cuts were

dredged through the stone pitching downstream of the Barrage, so as to allow of the downstream dams being founded on soil, and therefore tight. The dredging was done by a ½-cubic metre Priestman's dredger.

The outer upstream dam having been finished, the inner and downstream dams were made without any difficulty.

On February 27th the pumps were started, and by March 4th the clearing of the floor was commenced. The latter was the most laborious part of the whole season's work, as it embraced the removal of the cofferdam enclosing the ten arches which had failed, and the clearing away of the stone bar which had been made along the downstream floor for the purpose of holding up the water surface during preceding years.

Work was commenced over the whole area and carried down to a level of 1½ metre above floor.

Below that level the clearing was done over small areas only at a time, any area exposed being thoroughly cleaned and at once built on.

On March 24th the first stone of the repairs was laid under arch No. 4. On April 2nd, however, in attempting to lay the new floor upstream of the Barrage, and in the angle between it and the left lock, several springs broke out violently within six metres of the edge of the Barrage floor, and one very heavy spring broke out through the foundations of the lock wall. This wall was originally built by skipping concrete, composed of ordinary lime homra and broken stone, between two lines of sheet piling to a level 2·5 metres above the surface of the Barrage floor, the brickwork of the wall commencing at that level. The concrete appeared to have been skipped in very muddy water, and never to have set, as when part of a pile was sawed away, the concrete poured through the space so opened like rubbish shot out of a cart. The spring referred to came through the concrete and between the piles, bringing with it large quantities of very fine black mud.

During the day which was spent in getting in the new upstream apron and in carrying it up to cover the rotten piles of the lock wall, those piles bent forward about ·12 metre for a length of 20 metres; the concrete filling crushed down, and the wall above, which was 8 metres high, cracked badly and leant over out of plumb.

By the evening it became apparent that further pumping would probably result in the fall of the lock wall, and the water was therefore allowed to rise 2 metres. At that height the springs ceased to throw mud, and owing to this and to the pressure of the water on the soil outside the foundations, a certain amount of stability was obtained and time thus gained for further work.

When pumping was discontinued, the ground had been cleared for the upstream apron for its full width of 25 metres and for a length of 30 metres.

About half this area had been covered with rubble masonry to an average thickness of 1 metre.

Concrete composed of 5 parts of broken stone, 1½ part of desert sand, and 1 part of Portland cement, was then substituted for rubble masonry.

It was laid by tipping and treading down the tiphead. After two weeks, when the water was pumped down, the work was dug into and found to have well set.

The laying of the remainder of the apron gave no trouble. Springs occurred at a good many points, but they did not threaten the safety of the structure and they were all satisfactorily closed. Where the soil was of sand, the lower part of the

apron was built of rubble masonry in mortar composed of 1½ of pounded brick to 1 of lime. Where the soil was bad, the whole was made of rubble stone laid in mortar composed of 2 of sand to 1 of cement.

Concurrently with the laying of the apron, the repairs and additions to the existing floor were carried on. A great deal of difficulty was met with, owing to the ruinous state of the foundations of the bridge and to the tangled mass of rubbish of all sorts with which its floor was buried to the depth of 3 metres. The cofferdam, enclosing arches Nos. 5 to 14 inclusive, had partly tumbled down. It had been originally very strongly constructed and largely braced with iron rods. These had bent, and were interlaced with timber, stones, chains, and every conceivable form of débris. The removal of almost every timber of this cofferdam was followed by a squirt of water through the floor, and during its removal and the building of the new floor, the bridge itself cracked badly, evidence of considerable settlement.

The floors of the arches were raised to heights varying with the condition in which they were found to be. No. 9, which was the worst of all, was raised to R.L. 11·50. The springs under this arch were numerous and prevented the water being got down below 2 metres above floor. They were closed by the aid of iron pipes. The floor having been cleared of débris, silt, and rubbish as far as possible, ordinary cast-iron pump pipes 6 feet long were put into place, one vertically over each spring, and concrete was tipped to water-surface round them and over the whole area of the floor. Whilst this was being done, the water coming through the pipes was led away to the pumps in troughs and by channels previously prepared. When the concrete had set for six days, a trench 1 metre wide and extending from pier to pier was dug through the concrete down to floor level, a site having been chosen which was as far as could be judged sound. The floor was thoroughly cleaned and the trench was then filled in with concrete laid in layers and rammed. The object of this was to make a water-tight diaphragm extend from the old to the new floor, and thus to prevent creep of water between the two. The pipes were then filled with finely broken concrete metal and closed by ½-inch iron plates bolted on to their flanges, india-rubber packing rings being used to make the joint tight. The whole floor was then concreted over to the necessary height and the ashlar face laid.

One 12-inch, one 10-inch and two 4½-inch pipes were used in closing the springs coming through the floor of this arch, and although all precaution was adopted the arches cracked considerably during the progress of the work.

Arches Nos. 8 and 10 were also troublesome, the floor downstream of No. 10 being broken across diagonally in two separate lines—one of these lines was a crack for half its length widening out into a fissure 4 inches wide for a length of about 4 metres.

Where cracks of this sort occurred, they were staunched as follows: The broken floor was cleared of débris bit by bit and covered at once with sand to a depth sufficient to keep down the springs. It was then surrounded at a distance by concrete laid after thorough clearing on the sound floor and carried up to a level at which the springs could not break through it. The concrete was then pushed on inwards until it was stopped by the flow of water. When this occurred the sand was carried away as deep as possible, and rubble masonry laid in cement mortar was built on the sand, a trench about 5 metres wide being left coinciding with the crack in the floor. Concrete metal was laid a few inches deep, and on it a pipe 2 metres

longer than the crack, closed at one end and perforated with ½-inch holes along its under half circumference for so much of its length as coincided with the crack, was securely built into the new masonry for its imperforate length.

An outflow drain was left in the masonry in the prolongation of the pipe, and the water from the broken floor was thus passed through the pipe to the pumps. When the masonry had set, the pipe was covered in with masonry laid in cement gauged neat, and the whole then raised to a safe height. The end of the pipe was afterwards closed with an iron plate and the outflow channel built up.

Upstream of arch No. 11 and between its cutwaters no floor appeared to have been built, as no trace of it could be found at 1·5 metre below its proper level.

The floor downstream of the Barrage was found to terminate at the distance of 12 metres from the bridge in a row of piling. Such drawings of the work as exist show a talus of concrete extending downstream of this piling, but in one or two places only could traces of it be found. The piling itself for almost its whole length projected from ·50 to 1·25 metre above the floor, and along its line numerous springs existed. The piles were all sawed off to the level of the floor and covered with rubble masonry 1¼ metre thick, this masonry being carried downstream to a distance of nowhere less than 7 metres.

Downstream of arches Nos. 12, 13 and 14, the floor was extended to a distance of 22 metres beyond the piling, and downstream of arches 7, 8, 9, 10 and 11 it was carried to a distance of 30 metres.

The left upstream lock was protected for its whole upstream length by an apron of rubble masonry 1 metre thick, sloping from R.L. 12·00 at the wall down to R.L. 10·00 at a distance of 12 metres, a toe 2 metres wide and 1 metre deep being given to the whole length.

Parallel to the Barrage, and at a distance of 20 metres from the upstream edge of its existing floor, a row of sheet piling was driven for a depth of 5 metres, the new floor being carried over it for a width of 5 metres.

Cast-iron grooves in which the new drop sluice gates will work were fitted to the piers.

The repairs to the floors of arches Nos. 1 to 29 inclusive were completed by July 1st, on which date work was stopped by the rise of the river.

In all 5221 cubic metres of concrete, 12,985 cubic metres of rubble masonry, 412 cubic metres of Trieste stone ashlar, and 1491 cubic metres of Tura stone ashlar were laid. 133·6 cubic metres of piling were also driven.

The total expenditure on the work was 81,333*l.*

The unwatering was done by six 12-inch centrifugal pumps, two 10-inch centrifugals, and one 9-inch pulsometer. An arrangement of a 4-inch pulsometer mounted on a truck with boiler and flexible suction was found to be very useful in unwatering small areas.

The work was carried on during the day without holidays from December 2nd, 1886, to March 28th, 1887. From the latter date to July 1st it was prosecuted without intermission. The lighting employed was electric, 8 arc lamps of 2000 candles power each being employed."

"*Barrage repairs*, 1888.—During the working season of 1887 the floor of the western part of the Rosetta Barrage had been laid dry and repairs to it carried out as far as the early rise of the river allowed.

It was originally intended that the eastern part of the same Barrage should be put in order during the season of 1888, so as to complete one bridge before commencing another.

The extreme height, however, of the Nile in the flood of the previous year rendered a late fall probable, and the obstruction of the deep channel of the Rosetta branch became therefore inadvisable.

An additional argument in favour of taking up the east end of the Damietta Barrage existed in the necessity for putting in the foundations of the Rayah Tewfiki Head Lock and Regulator, and as this work is adjacent to the river, the laying dry of a large area of the river bed immediately outside its foundation pit would result, it was thought, in an economy of pumping.

Yet a third argument existed in the need for completing a portion of the downstream apron of the west end of the Rosetta Barrage, and for strengthening the lock at that end; both of these works having been interfered with by the early rise of the river in 1887.

These arguments determined that the eastern end of the Damietta Barrage should be taken up in 1888, and accordingly, on December 1st, 1887, work was commenced on the dams.

The scheme of the work was identical with that carried out on the Rosetta Barrage during the previous year, both as regards the work itself and the manner of execution. The area to be dealt with was enclosed within double dams, those upstream having their crests at R.L. 14·50, and those downstream at 12·50. The former were made in water from 3 metres to 7·5 metres deep, of clayey silt dug from the island upstream of the Damietta Barrage, and proved to be very tight. The latter were made from the silt deposited yearly under the western arches of the bridge, and during the progress of the work they gave much trouble and anxiety.

On February 10th the upstream dams were closed, on February 17th the placing of the pumps in position was begun, and on February 25th fires were lighted.

As at first constructed the dams enclosed 35 arches, and the area being too large to work at, it was subdivided into three portions by small dams running parallel to the course of the river.

One only of these pockets was pumped down to floor level at a time, the water in the others being kept at different levels so as to reduce to a minimum the pressure on each dam.

On March 9th the floor of the fifteen eastern arches was laid dry and work was at once begun. It was pushed on with vigour and continued without intermission until June 20th, by which time the floor of forty-one arches and of the east lock had been put in order.

The condition of the Bridge was much better than that of the Rosetta Barrage, but this seems to have been due solely to the fact that it had not been subjected to the same strain.

The evidences of scamping were greater than any found on the Rosetta, and the failure of the work, if it had been left unrepaired, could only have been a matter of time.

The east lock was found to have small holes in its floor over the whole area

downstream of the lift wall and immediately at the foot of the lift wall, no floor existed over an area of 7 metres by 5 metres, nor could any trace of one be found at the depth of a metre below surface level. It was accordingly decided to raise the floor of the lock with cement concrete faced with brick on end and ashlar, the whole thickness so added being 0·72 metre. The small holes were first closed with wooden plugs and the new face then carried over them. Immediately below the lift wall the area without original floor was enclosed by a brick wall built in cement to a height of 2 metres. At this height it was found that the springs worked with insufficient force to throw mud, and so the whole area was excavated by divers to a depth of 1 metre and concreted over, each spring being enclosed in a pipe.

When set the pipes were closed and the new floor built to a minimum thickness of 1·8 metre, sloping upwards near the lift wall, 1 in 7, to a thickness of 3·3 metres. The necessary thickness of floor was thus gained by the substitution of a slope for the vertical lift wall, and danger to boats by their grounding on a floor of sudden variation of level was obviated.

On the floor of the bridge itself several singular points were brought to light. Under many of the arches and in the floor downstream of them numerous holes existed.

They were caused by the omission of one brick on end, and from the freedom with which many of them threw water, they appeared to pass completely through the floor. They were in rows regularly spaced and resembled weepholes. Some of them were silted up so as to be quite water-tight, whilst others threw a full bore of mud and water to a height of nearly 2 feet. Under arch No. 71 and in the floor downstream of it there were 37 of these holes, and between three and four hundred in the forty-one arches dealt with. They were each closed by driving in a wad of tow with a tapered wooden plug. When home the plug was sawn off level with the floor and covered with rubble masonry laid in cement.

Arches Nos. 37 and 38 were found to have no floor. The concrete of the foundation appeared to have been skipped in and left at a level of about ·5 metre below floor. The top of this concrete was rough and of very bad quality, the mortar and the metal having separated and formed into strata and pockets like a much disturbed geological formation.

It was levelled down, and all very bad portions were removed to as great a depth as was possible with safety. New work was then built to a thickness of 2·25 metres.

The dams as originally constructed enclosed thirty-four arches only. As work progressed new dams were thrown out so as to enable the repairs to be carried past the centre arches, leaving so little work undone as to make the completion of the bridge as far as possible a certainty in one more working season. These extensions, as before stated, enabled the eastern forty-one arches, together with the end lock, to be put in order.

The work done was as follows:—

The whole of the existing floor of the Barrage, both upstream and downstream as well as under the arches, was raised from R.L. 8·25 to R.L. 9·5 with the exception of arches 70 and 71, which, owing to the badness of their floors, were raised to R.L. 10. This was done as on the Rosetta Barrage, with concrete in cement faced for a length of 7 metres under the gates with Trieste stone ashlar and elsewhere with

ashlar of old Cairo stone. This new floor was carried upstream and downstream beyond the arches to the limits of the original floor. An upstream apron of rubble masonry 25 metres wide and 1 metre thick was added, a row of piles being driven at 5 metres within its upstream edge to a depth of 5 metres below its underside. On the downstream side an apron was also built. Its thickness was 1·5 metre, and its width 10 metres from arches 42 to 71 inclusive, whilst from 31 to 42 the width was increased to 15 metres and the thickness to 2 metres on accountof the badness of the soil.

The lock walls both upstream and downstream were protected with an apron 12 metres wide sloping from R.L. 12·0 at the wall to R.L. 9·5. Along the whole of the downstream edge of the floor, and at a distance from it of 5 metres, a row of rubble masonry blocks was built, each block being 5 metres by 3 metres, by 1·5 metre, the space between this row of blocks and the edge of the floor being filled in with dry stone pitching covered with a layer of rubble blocks 2·5 metres square, and ·75 metre thick. Beyond the outer line of blocks pitching was put in wherever there was place for it up to the level of the floor.

During the execution of this work, the greatest sources of trouble were the original lines of piles between which the floor had been built. As on the Rosetta Barrage these piles had been left projecting about 1 metre above the top of the floor, and from end to end of the work done they formed an almost unbroken line of springs. Driven as they were through the upper stratum of clay into the underlying mud and sand, and left projecting high into the rush of the water, the downstream line of piles seemed to have been shaken loose, and each separate pile became a lead for an upward rush of water. The shutting down of this water proved very troublesome, particularly in the centre of the river. It was effected by enclosing each separate jet in a pipe of suitable size surrounded with masonry.

When the masonry had set the pipes were closed and built over. Downstream of arches Nos. 34 and 35, in a length of 14 metres 59 pipes were used, two being 12 inches diameter, three 6 inches, and the remainder 1 inch to 3 inches. The soil at this part of the Barrage was very bad, and this added considerably to the difficulty of the work, as a spring when stopped at one spot invariably broke out at others. So soft, in fact, was the soil at the middle of the Barrage that every blow of the pile drivers working upstream was plainly felt on the bridge.

The work was completed by June 20th, and on June 25th the last pump was removed. The quantities of work actually done were: concrete 7788 cubic metres, rubble masonry 15,867 cubic metres, Trieste ashlar 541 cubic metres, old Cairo ashlar 2001 cubic metres, and brickwork 396 cubic metres, or 26,593 cubic metres in all.

Iron grooves were added to the piers of the 41 arches, and a curtain of sheet piles was driven parallel to the upstream face of the bridge. The gates of the east lock also were put in order and painted.

The unwatering was a heavy item. It was done by nine 12-inch and three 10-inch centrifugal pumps. A 9-inch pulsometer kept down the water between the two upstream dams, whilst two 4-inch pulsometers on wheels, and numerous hand pumps, were employed on drying small areas.

The pile driving was mostly done by hand ringing engines. A steam driver was, however, put to work when about one-half the piling was finished, and it was found to send the piles home at about one-third the cost of the hand drivers.

The electric light was started on February 26th, and was employed without intermission until the end of the work. Although but little concrete or masonry was done at night, a great deal of work went on in maintenance of dams, carriage of materials from the stacking yard to the site, and in general preparations for the following day. One assistant engineer and one head overseer were invariably on the works all night, and the number of workmen employed at night from the beginning of March till the end of May was never less than 800 and often rose to double that number.

On the Rosetta Barrage some work was also done. As was stated at the commencement of this report, a portion of the apron downstream of the arches 1 to 6 was not carried to its full extent, during the working season of 1887, nor was the lower floor of the west lock put in order.

To remedy this a dam was run along the ten western arches upstream of and in contact with the piers, and a corresponding dam was carried parallel to it downstream of the bridge, at a distance sufficient to enable the work to be done. These two were joined by a dam parallel to the direction of the stream and the included area was then pumped out.

The whole area was covered with rubble masonry as intended, the springs which had given considerable trouble during the previous year were closed, and the apron downstream of the western arches was satisfactorily completed. The floor of the lock was laid dry, and was found not to be in a bad state except at the tail. There a double line of sheet piling extending across it up to the level of the upper floor closed completely the lock as a low river one and served as leads for numerous springs. These piles were cut away and built over, the level of the floor being raised from 8·15 to 9·00. An apron 10 metres wide was also carried across the tail of the lock and round the lock wall to meet the apron of the bridge. During the progress of the work some anxiety was caused by the cracking of the lock wall, due to the removal of the soil on which it was built by heavy springs. 2,676 cubic metres of rubble masonry were laid in thus completing the floor of the west end of the Rosetta Barrage.

The bridge itself had originally failed owing to the break up of the floor, and this failure manifested itself on the superstructure by cracking in 10 arches, and by depression and horizontal displacement extending over a length of 15 spans. Each year when the water was headed up these cracks enlarged, and when the work was taken up by this service, five of the arches had been centred up to prevent chance of accident. The vertical settlement amounted at that time to ·15 metre at its greatest point, the horizontal displacement being ·19 metre. During the progress of the work it was found necessary to put centres in five additional arches, as they cracked so badly as to place the men working below in danger from falling bricks. On attempting to remove the centres it was found that many of the bricks of the arches were completely loose, and the repair of the arches themselves was necessary. In fixing the centering each lagging had been wedged off the centres separately, and could, therefore, be removed independently of any other.

In carrying out the repairs one lagging was removed at a time, and if the arch behind it was sound, it was replaced and again wedged up. If a crack was uncovered it was raked out and pointed. Where a badly broken portion of the arch was uncovered, it was removed in parts and rebuilt from below to a depth of one

and a half bricks. In every case the lagging was replaced as soon as the work was done. When an entire arch had been thus treated, the earth filling and backing were removed, and all cracks and broken brickwork opened out and rebuilt from above, down to the top of the new work put in from below.

When the whole of the arches were finished, they were allowed one month to set and the centres were then removed.

No sign of any settlement has since shown itself. Ten pairs of the new gates were put in place, and the arrangement of tramway intended to carry the traveller for working these gates was put up over twenty bays. 288 cubic metres of brickwork, 65 cubic metres of ashlar masonry, and 117 tons of ironwork were erected for this purpose. A traveller of the design proposed for working the gates was obtained and found to work satisfactorily."

"*Barrage repairs*, 1889.—The work done on the Barrage during the season of 1889 consisted of the repair of the floor of the eastern portion of the Rosetta, and of the fittings for gates on the eastern half of the Damietta.

On the Rosetta an exceptionally early fall of the Nile enabled work on the dams to be begun on November 2nd. This was extremely fortunate, as the depth of water was everywhere considerable, and for a distance of 100 metres it averaged 12 metres, reaching for a length of 25 metres to a depth of 15 metres.

On tipping the light soil which alone was available, it was found to take a very flat slope in the deep water, the bed of the river being appreciably raised at a distance of 100 metres from the centre line of the dam. As this resulted in great expense and loss of time, a pair of parallel banks were formed at 40 metres distance from one another, between which the earth of the dam was afterwards tipped. The upstream of these banks was made of brick rubbish and spawls, and was carried up to R.L. 9·0, or 4 metres below water surface. The downstream bank was made of sand bags, and was carried up to water level. In all, nearly 90,000 sacks were used on the dams.

The portion of the Barrage worked on was that founded on a bank of stone stated to be in one place 15 metres high. Some anxiety was felt as to whether this stone bank was silted up sufficiently to be as water-tight as the surrounding river bed, as if not, it would prevent the division of the area within the dams into separate ponds, and it might also, by allowing a free passage to the water lying at a low level, overpower the pumps. The bank, however, proved tight and no trouble resulted from its existence.

The dams embraced the whole of the unrepaired area of the Rosetta Barrage, consisting of 39 arches and the East lock of 15 metres width. They were carried far enough to the West to enclose also four arches which had been repaired in 1887. This was done to enable any part of the unprotected end of the previous new work to be repaired should damage to it prove to have been caused by the two flood seasons which had passed since its construction.

The dam parallel to the axis of the river thus crossed the extensions to the original floor and the pitching at right angles. Downstream of the bridge the pitching was dredged away by two Kingston's dredgers to a depth at which, judging by the appearance of the stone brought up, it had silted solid.

On ultimately closing the dams and pumping out the enclosed area, the downstream dam proved perfectly tight, and throughout the work gave no trouble.

But the pitching crossed by the dam upstream of the bridge being very small in sectional area was not dredged away, and it was further believed that as it was remote from the draw of the Barrage it would have been silted up.

Such, however, did not prove to be the case, and on the water inside the dams being lowered, the dam began to slip on both its outer and inner faces. A spur of earthwork was run out from the dam, completely covering the pitching, and when this spur had reached a length of 25 metres the leak through the dam stopped and no further trouble ensued. For some hours, however, the dam was in serious danger, and as the date was February 24th, an accident would have caused greater loss than the mere cost of repair.

Owing to the great depth of water in which the upstream dam had to be constructed, it was determined not to make a second dam, but to trust entirely to one. As the level of the water upstream had to be kept to 13·00, and the pumping inside the dams carried down to R.L. 7·75, this single dam had to withstand a head of 5·25 metres, and this it did very satisfactorily for a period of four months.

On the completion of the outer dams the enclosed area was, as heretofore, divided into three ponds by banks parallel to the axis of the river, and on February 24th, 1890, pumping was begun at 6 p.m.

The condition of the floor was found to be sounder than at any part of the Barrage previously taken up, but at the same time, owing to its having been exposed to the heaviest current of the river, its surface was more severely cut than at any other place. The brick facing was in many places cut completely through, and everywhere the surface was scored in lines 15 to 20 centimetres deep.

The usual evidences of careless treatment were found in the existence of deep holes and furrows cut by chains which, having fallen, had been allowed to remain on the floor. Unless in the future the Barrage is better worked than it has been in the past, serious damage will result. With the upstream gauge maintained to R.L. 14·00, the scour will be at times very heavy, and if a chain be allowed to vibrate on the floor it will bore a hole in a single month deep enough to seriously affect the safety of the bridge.

The work done was identical with that of previous years. The floor was raised to R.L. 9·0 everywhere except under nine arches. These nine were sound, but much cut, and as their surface was already at R.L. 8·60 in the centre and 8·85 at the piers, it was found advisable to put in the new work to R.L. 9·20, so as to obviate the necessity of cutting away any of the old floor in order to make room for the new ashlar facing. This enabled the invert to be levelled up with concrete to form a bed for the new masonry.

As stated above, the work done was similar to that of previous years, and consisted of the raising of the existing floor and its extension up and down stream to the same distances as before. When this was completed, a line of blocks of masonry was placed along the toe of the work done in 1887.

To enable these blocks to be put in, a dam was run along the downstream floor for a length sufficient to allow of five or six blocks being built, and the usual enclosing dams were formed. The leakage of the gates was allowed to pass round each end of the dam on the floor, and the area enclosed by the dams was pumped out.

The excavation for the foundations of the blocks was a severe test of the soundness of the work done in 1887, as the upstream gauge was maintained by the

gates to R.L. 13·0, whilst the unwatering at the downstream edge of the apron was carried to R.L. 7·50; a head of 5·50 metres was thus put on to the work and no sign of weakness could be anywhere detected.

The total quantities of work done were :—

	cubic metres
Rubble masonry	12,499
Concrete	3,254
Trieste ashlar	319·2
Old Cairo ashlar	998·4
Brickwork	284

After the rise of the river, the fittings for the new gates where erected and the Rosetta Bridge completed. With the exception of the pitching, which must be added from year to year as necessity arises, the Rosetta Barrage is complete, and needs only careful and skilful regulating to prove a success. At the same time the soil on which the bridge is built is so feeble, the depth of the original foundations so slight, the weight of the superstructure so great, the pressure due to heading up so large, that any recklessness of treatment will be followed with disastrous effects."

"*Barrage repairs*, 1890.—The work that remained to be done in the winter of 1890 was the completion of the left half of the Damietta Barrage.

In this portion there were 30 arches untouched, but it was resolved to permanently close the ten western arches so as to prevent the necessity of regulating on them. This involved the closing of the western lock also.

The closure was effected by a revetment wall joined on to the pier of the 11th arch from the west bank, which was thickened and prolonged 20 metres downstream. The wall is 3·30 metres at base and 1 metre at top, with a batter of one-twelth on the river side. A toe of 5 metres width and 0·75 thick is given at R.L. 9·50 metres, and the top of the wall is at R.L. 19·00. Its length is 120 metres. The foundations are on wells 3 metres deep.

The earthern dam was begun on January 10th and finished up to R.L. 14·50 upstream on February 7th. The earth was brought from the island and from the Rayyah Taufiqi head. By February 26th the old floor was thoroughly cleaned and pitched over and concreted and the springs stopped. The old piles at the ends of the floor were sawn off to R.L. 8·00, and the new masonry floor in extension of the old one was in full progress. A very serious spring was met with in bay 17 which had to be most carefully plugged with cement. This spring was then covered with masonry and then the Trieste stone was laid on it uniform with the rest of the Barrage floor.

The extension of the floor was as usual of rubble masonry in cement, great care being taken to make the join on to the old work perfect. The bays Nos. 20, 21, 22, 23 were much scoured upstream, and concrete had to be lowered in skips to make a foundation, on which the floor was eventually laid.

The line of old piles downstream proved very troublesome, as between them there were innumerable springs, all of which had to be closed by passing them through pipes and building round the pipe. In the bays 21–30 (old numbers), owing to the very insecure and treacherous subsoil, the new floors were raised to 10·00, with slopes on either side down to the level of the rest of the Barrage. The work progressed well without any accident until March 25th. On the night of March 25th–26th, a spring broke out at the edge of the upstream apron of the

work of season 1888, and though insignificant at first, it gradually gained on the engines, and it was found necessary to abandon the works at 2 a.m. It was found that there existed a free communication diagonally under the floor of 1888 from the river under the earthen dam. Early on the morning of the 26th the dam sank 1½ metre, clearly proving the passage of water under it and in contact with the earth.

It was afterwards found that the spring had gradually removed the earth from under the apron of 1888, and that the apron broke by the weight of the dam, thus causing the dam suddenly to sink alarmingly. The crack in the floor apron extended from bay 40 to bay 34, where it was only 15 metres from the cut water.

It was in this length in 1888 that the floor had to be laid on an old stratum of lumps of half set mortar and concrete metal left there by the original Barrage builders.

A long dam was made, extending parallel to the Barrage to bay 44. The closure was made on April 14th, and on April 16th work was again started inside the old dam. Between the old and new works a dam was maintained to minimise the strains.

The greatest precautions were taken to keep the arches closed in which no work was going on in case of a sudden breach of the dam. The last stone of the Barrage floor was laid on May 26th. The broken floor which had sunk was covered with masonry up to R.L. 9·50. It was found that in front of ten arches the upstream floor had broken off clean and sunk 1·50 at the deepest part, and the whole mass was much fissured, and from each crack a spring issued. These were all closed with great difficulty, but now this portion is of great thickness and very strong."

After the completion of the repairs by Colonel Western and Mr. Reid, the level of the water held up by the Barrages was raised from R.L. 13·00 to R.L. 14·00 metres.

Considering that the canal heads upstream of the Barrages have regulating heads, it would have been possible immediately the Barrages were repaired to distribute the water between the different canals, according to the area commanded by each. As the public, however, would have objected to the main canal heads being regulated on, a temporary feeder for the Royal Menoufia was excavated. This feeder has done little to rectify the inequalities of supply, and before long it will be necessary to revert to the scientific method of distribution.

The following selections are from Major Brown's book on the Barrage, entitled 'The History of Barrage,' and published by Messrs. Diemer, of Cairo:—

"The new system of regulation adopted in the restored Barrage consists of wrought-iron gates provided with rollers sliding in cast-iron grooves fixed in the piers. Since the maximum depth of water on the floor is 4½ metres (14½ feet), each opening has been given double grooves and two gates, of which the upper one is always 2½ metres high, and the lower one in the Damietta Barrage 2 metres. In the Rosetta Barrage the height of the bottom gate varies from 2½ to 1 metre in height, on account of the

floor having been raised to different levels during the repairs. In one arch, No. 9, there is no bottom gate at all, the floor level being at R.L. 11·50. The top of the upper gates, when the Barrage is closed, is at R.L. 14·00, and of the lower gates at R.L. 11·50 throughout. The floor of the Damietta Barrage is at R.L. 9·50 in every archway: that of the Rosetta Barrage varies in different arches from R.L. 11·50 to 9·00.

The gates are lowered and raised by means of powerful crab winches (of which there are two to each Barrage) travelling on continuous rails.

For record sake I give below the varying levels of the floor on the Rosetta Barrage.

	metres	
At R. L.	9·00.	No. 19 to 22, 24 to 25, 27 to 45, 55 to 61.
R. L.	9·20.	No. 46 to 54.
R. L.	9·50.	No. 1 to 6, 12 to 18, 23 and 26.
R. L.	10·00.	No. 7 and 11.
R. L.	10·50.	No. 8 and 10.
R. L.	11·50.	No. 9.

The arches, throughout this note, are numbered from west to east.

The total cost of this restoration for both Barrages was 465,000*l.*

The quantities of masonry executed were :—

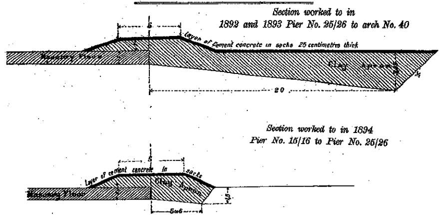
	cubic metres
Concrete	23,863
Rubble masonry	54,411
Ashlar masonry	6,983
Brick masonry	2,680
Dry rubble pitching	25,460
Total	113,397

In May 1891, when the Damietta Barrage was holding up 3·18 metres of water, seven springs appeared along the downstream edge of the masonry floor opposite bays 20, 21, 22, 25, 26 and 37; and it was ascertained by experiments that these springs arose from water which was passing under the floor from upstream of the Barrage. (It may be noted here that, according to rumour, this portion of the Damietta Barrage is founded on tipped stone like the right flank of the Rosetta Barrage.) A large inlet was discovered in front of bay 29–30. The inlet crater was filled with sacks of sand and an island of soil formed over it up to water level, and the upstream apron floor was also covered with soil. This weakened but did not stop the springs, as the soil was too light, but further work had to be postponed till the next season.

The following system for stopping the leaks was eventually adopted by Mr. E. W. P. Foster, late Inspector-General of Irrigation in Lower Egypt. A trench of the dimensions, given in the cross section of the floor, was cleared of its rubble pitching and porous soil by dredging along the upstream edge of the floor in front of from three to five bays at a time. This trench was then filled with stiff clay deposited in layers of half a metre thick, pressed down by means of a sledge drawn over it, to form an impervious curtain. Over the junction between the clay and the masonry floor a broad clay bank one metre high was formed, and consolidated to make a tight joint: it was then covered with a layer of sacks filled with

DAMIETTA BARRAGE UPSTREAM CLAY APRON

Scale



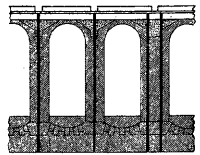
Note: The work of 1892 (Pier 25/26 to arch 35) was not consolidated by the sledge, except only that part of it, which was taken up and relaid in 1896.

Dimensions in metres.

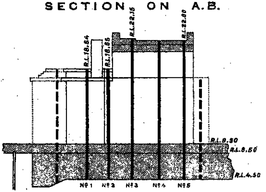
DIAGRAM

Showing bores made in the Barrage piers.

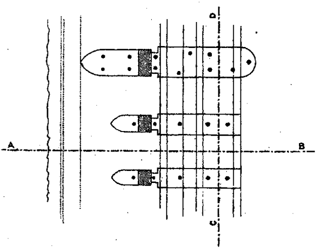
SECTION ON C.D.



SECTION ON A.B.



PLAN



concrete and laid close together to protect the surface of the clay from erosion by the current. Great care had to be taken that this joint was properly cleared of loose material before the clay was laid on it, and that the concrete in sacks was carefully bedded and arranged. To do this a diving bell was made use of. Careful soundings made in 1895 over the whole area of concrete sacks showed that they had not been displaced by the flood."

The following selections are from Major Brown's Reports on the Barrage maintenance for 1896 and 1897. The repairs executed in these two years were particularly interesting:—

"*Barrage repairs*, 1896.—The most important and interesting operations undertaken during the year were those conducted on the recommendation and according to the directions of Mr. W. R. Kinipple, M.Inst.C.E. The system, known as stock-ramming, as it was applied to the Damietta Barrage, consisted in forcing plastic clay under the foundations with the view of filling up all cavities or leads through which leaks may find their way under the floor, thereby forming everywhere a tight junction between the under side of the masonry and the surface of the sand substratum on which the Barrage rests. It was decided to experiment on ten bays of the Damietta Barrage and on an equal number of the Rosetta, and to select those lengths of each Barrage downstream of which springs appear whenever a considerable head of water is held up by regulation.

The first necessity was a suitable clay, and after much search and many failures, an excellent clay was discovered by Mr. Verschoyle, in the bed of the Edku drain.

The method adopted for getting the clay below the foundations and for inducing it to spread when there, was the following:—

Three 5-inch diameter holes, 3·30 metres apart, as shown in the accompanying diagram, were bored in the length of each pier of the ordinary width of 2 metres. In the three central piers of the Damietta Barrage, which are 3·60 metres wide, double lines of bore-holes were made. The holes thus arranged were 7 metres apart in adjacent piers. The height of each bore-hole from roadway to under side of floor was about 17 metres.

Operations were begun on the Damietta Barrage. The borings showed that, generally speaking, the Barrage was resting on fairly clean coarse sand of a much better quality for foundations than had been generally supposed. They also disclosed the fact that the bottom of the floor was at most points 70 centimetres higher, that is, that the floor was 70 centimetres less in thickness than the original design shows. The underside of the foundations was also found to be uneven, varying in level as much as 50 centimetres at half a dozen points. The extreme limits of level at which the boring tool pierced the concrete were R.L. 6·60 and R.L. 4·45, a range of 2·15 metres.

When the bore-holes were complete, they were lined with iron tubes to prepare them for stock-ramming. The clay was worked up and made into charges in a mould: four charges at a time were then let down to the bottom of the bore-hole and forced downwards by the weight of an iron rammer. Nine metres length of the bore-hole was always full of water, so that the rammer was prevented by the water cushion from falling with any violence. As much clay as could be made to spread out at the bottom of the bore was introduced into each hole and rammed. There

was thus squeezed into the cavity below the centre pier as much as 2½ cubic metres of compressed clay, by which the pier must be supported at points where it had no support before, and possibly a leak be intercepted.

Under all other bore-holes in the Damietta Barrage sand existed, but no distinct cavity, though the sand was found at the foot of a few bores to be so loose as to allow the boring tool to drop by its own weight, in one case as much as 65 centimetres.

In the case of every hole as much clay was forced down as could be made to move, with the view of at least tightening up anything that might be loose in the neighbourhood of the bottom of the bore. The number of charges of clay inserted in each hole varied from 40 to 983, about 800 charges going to make a cubic metre. As a final operation the holes were filled up with compressed clay to R.L. 9·50 (the level of the floor of the Damietta Barrage), over which water was filled in to R.L. 15·00 to create a constant downward pressure.

While working on piers 18–19 to 22–23, a free water communication under the floor between certain holes was detected, in one extreme case between holes 28 metres apart. As stock-ramming proceeded, the evidences of communication ceased, showing that the clay had blocked the connecting channels.

The cost of these experimental operations was 2686*l.*, including Mr. Kinipple's fee, the cost of boring 500 metres of bore-holes on the Rosetta Barrage, of clay collection, and of tubes and certain plant not used in the work on the Damietta Barrage. Deducting these the cost of the operations per bore-hole becomes 20*l.*, which gives 60*l.* per pier of 3 holes.

To treat the remainder of the two Barrages in the same way would cost about 7000*l.* altogether, but it is probable that the experience gained during the experiment will cause the adoption of some more effectual way of applying the principle of grouting or stock-ramming (or a combination of both) to remedy the defects in the Barrage foundations.

The experimental work on the Damietta Barrage having been completed, attention was turned to the Rosetta Barrage. As it was felt that the clay stock-ramming operations on the Damietta Barrage were not entirely satisfactory, and that the success of the experiments was but partial, it was decided to employ the method of grouting with cement on the portion of the Rosetta Barrage prepared for experimental work. Holes, similarly situated to those on the Damietta Barrage, had been bored on the centre lines of eleven of the western piers down to R.L. 7·00; that is, to a point 2·50 metres above the theoretical foundation level of R.L. 4·50.

In the case of a bore-hole in the pier between arches 8 and 9, the boring tool on reaching R.L. 8·00 fell 1 metre, thus indicating the existence of a cavity. It was decided to commence operations on this hole. By means of the sand pump loose concrete metal and separate lumps of very inferior mortar were brought up from the bottom of the bore until the cavity had been cleared down to 2·30 metres below the level at which the concrete was pierced. It was not thought wise to go on clearing any more, and it was decided to grout up the hollow with pebbles and cement. The grouting continued till the cavity had absorbed 29 barrels of cement and about half a cubic metre of pebbles.

The two other holes of this pier, middle and south, were then bored through and a cavity of 68 centimetres depth found under the middle bore, and 49 centi-

metres under the south one. Pure cement grout without pebbles was then poured down the middle hole until 35 barrels had been expended. The south hole took 6 barrels to finish the grouting of this pier.

The two neighbouring piers were similarly treated.

It was calculated that the maximum column of grout obtained when the bore was full up to roadway level produced a pressure of 1·86 ton per square foot on the under side of the floor, a force sufficient to drive the grout into all vacant places from which the water could find an escape.

There was unmistakable evidence of the grout having travelled over 7 metres from below one bore-hole to another in the adjacent pier. There is no room in this report for details, but the effect of the experiments was to produce in the minds of those who superintended the operations a strong impression in favour of cement grout versus stock-rammed clay for strengthening the body of the Barrage.

The cost of the operations on the Rosetta Barrage was as below:—

Boring 500 metres	£85
Lining one hole	3
123 barrels of cement used in grouting three piers	71
Labour in grouting the three piers	6
Total	£165"

"*Barrage repairs*, 1897.—During the latter part of the year five bores were made in the length of every one of the piers of the Rosetta Barrage, and a double row in each of the wide central piers and in each of the flanking lock walls. Actual grouting operations began on the 23rd October and continued till the 1st January, 1898, when the last hole was grouted.

The eastern half of the Rosetta Barrage, according to the records that exist, was founded on a heap of rubble thrown into the deep channel of the river. This probably accounts for the large amount of cement absorbed by the bores of the ten piers at the east end of the Barrage, the five holes of one pier alone having taken 439 barrels, and the pier next it 337.

The theoretical level of the under side of the floor is R.L. 4·70. It was not easy to tell exactly at what level the boring tool pierced the concrete of the floor, especially where the Barrage rested on rubble, so the bore was carried down and cleared to a depth well below the lowest possible level of the floor, and at the west end where the concrete layers of the foundation were found to be supported by layers of sand, a pricker was driven down, sometimes to below sea-level, to make sure that the bore had been carried through the lowest concrete layer to the sand below. If it was found difficult to clear the bore of sand down to the desired level, the bore was lined with iron pipes which were driven well down into the sand, and the pipe then cleared. When the clearing was complete, the pipe was filled with cement-grout up to the top; it was then withdrawn and more grout poured into the unlined bore until it rose to the top.

Altogether the aggregate length of holes bored and grouted in the Rosetta Barrage was 5700 metres, and the number of barrels used in grouting was 3254. These figures include those of the previous experimental season. The cement used was North's 'Condor' branch, a slow-setting cement of excellent quality and well adapted to grouting.

In the west half of the Barrage the original concrete foundations seem to have broken up in places into layers (probably through being undermined by water passing underneath). These detached layers appear now to be separated by layers of sand, e.g. in pier 3/4 hole 4, and pier 5/6 hole 3, and pier 8/9. The boring was carried right through the lowest layer of hard material encountered, and the bore cleared to generally about R.L. 2·00, but often lower, as low even in one case as R.L. 0·20 Towards the east end, where the Barrage rests on the loose rubble mass, it was considered sufficient to carry the bore into the heap of rubble, and to stop clearing when the pump brought up clean broken stone without sand or boring chips. Towards the end of the season's work at the west end of the Barrage, it was discovered that it was often a more expeditious and effective way of clearing the bore to drive the sand down with the boring tool to the depths required, than to clear out the bore with the sand pump. This experience will probably save us a considerable amount of time and trouble when we are at work on the Damietta Barrage.

The most remarkable evidences of grout travel were in 'West Lock Pier,' holes Nos. 4 and 5 to No. 3, hole No. 7 to Nos. 9 and 10, and pier 31/32 hole 4 E to hole 4 W. In this last case the grout from hole 4 E passed under or through the foundations and rose up hole 4 W until both holes were full to the top, without pouring any grout into hole 4 W.

The cost of the work has been as follows :—

Boring 5700 metres at 15 piastres * a metre	£855
Barrels of cement, 3254 at piastres * 55¼	1798
Labour and supervision	300
Tools and stores	100
Total	£3053

It is proposed to treat the Damietta Barrage in the same way, and it is estimated that the cost will be 2772*l*."

The following selection is from Sir William Garstin's Report for 1897 :—

"In last year's note I stated that the most effectual way of rendering the Barrage safe would be to permanently reduce the head of water thrown upon it during regulation, and this could best be done by building supplementary dams downstream of it, and thus dividing the height to which the water was held up into two parts. This scheme eventually assumed a definite shape, and a project was prepared and submitted to the Caisse de la Dette. The latter, in December 1897, granted a sum of 530,000*l*. for the construction of the two weirs in question. The necessary work will be commenced in 1898, and it is hoped that they will be completed by the summer of 1901.

The design of these weirs may be briefly described as a core of rubble masonry in cement, sunk well below the bed of the river, and protected up and down stream by a long slope of rough stone blocks or pitching. The masonry core will be rendered water-tight by a mass of clay puddle upon either side of it. The weight of the pitching upon this puddle will tend to compress it, and this will, it is hoped, effectually prevent the passage of any springs through or under the work.

* 1*l*. = 100 piastres.

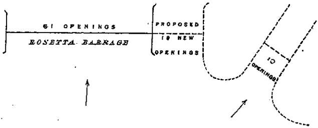
Each weir will be provided with a lock for navigation purposes. Neither of them will be brought up to their full height at first, but will be constructed, so to speak, in layers. The object of this manner of working is, that the afflux caused by such an obstruction in the river may be calculated and measured from actual observations before a level for the crest of the weir shall be finally decided upon. They are so designed that the head of water on the Barrage, which at present, during times of greatest pressure, amounts to 4·00 metres, shall be reduced so as not to exceed 2·5 metres. It is further intended to raise the gates of the existing Barrage, so that a water level of 15·50 may, when necessary, be retained upstream of the structure. Early sowing of the maize crop will thus be greatly facilitated, and all possible advantage taken of the rising flood."

These weirs are supposed to perform two works: (1) to allow of the head of water on the Barrages being reduced to 2·50 metres, when the upstream water level is R.L. 14·00; and (2) to permit of the upstream level of water on the Barrage being raised from R.L. 14·00 to R.L. 15·00 in June and July. With respect to the first reason, it may be stated that the Barrages would be competent to hold up water to R.L. 14·00, for that would mean a head of from 3·50 to 4·00 metres, provided only the downstream water level were ensured from retrogression owing to the river scouring out deep channels in parts of its bed. In 1886 I proposed the construction of loose stone platforms, at 1 kilometre distances below the two Barrages. These platforms were to have been each 50 metres wide, with their crests at R.L. 10 or 10·50. They would have cost 30,000*l.* If they were to be constructed to-day they would cost between them 30,000*l.*, and be, I think, as efficient as the new works estimated to cost 530,000*l.*

As far as the second reason is concerned, I may state that every page of Chapters VI., VII. and VIII. protests against the further raising of the water surface of the main canals in the middle reaches of the Delta. One sees vistas of new areas of saturation and new drains with the same sensation that Macbeth saw Banquo's progeny. The June and July supplies are undoubtedly important, but they should be supplemented I think, as explained in Chapter VII., by new works on the branches far down their courses, but not by additional summer supplies at the heads of the canals. A subsidiary weir at Samanûd, or Zifta, would, in my opinion, meet the requirements of the Damietta branch far better than any work at the head which had as its direct result the raising of the water level at the heads of the canals in June and July.

In Chapter XI. will be found an explanation for the recent heavy silt deposits in the Rayah Menoufia. As the river is now being trained directly on to the two Barrages, and as a triangular island is to be left in the middle of the river on their upstream side, the Rayah Menoufia head will be out of place. It might, with advantage, be removed to the left, up against the right flank of the Rosetta Barrage. When, moreover, we con-

sider that the Rayah head has only seven openings of 4½ metres each, while it should be provided with ten openings of 5 metres each, a new head would be a great improvement. Again, the Rosetta Barrage with a mean width of river of 450 metres has only sixty-one openings of 5 metres each, while the Damietta Barrage, with a mean width of river of only 250 metres, has also sixty-one openings of 5 metres each.* To the most casual observer of the Barrages in high flood, the inadequacy of the Rosetta



Barrage is as apparent as the unnecessary length of the Damietta Barrage. As the Rosetta branch has steadily increased in size and the Damietta diminished since the Barrages were constructed, this discrepancy continues to be aggravated. The only remedy is to increase the waterway of the Rosetta Barrage. This latter work should have at least eighty openings of 5 metres each, instead of the existing sixty-one openings. This would mean an additional nineteen openings. Advantage might be taken of these requirements to lengthen the Rosetta Barrage, and build the new Rayah head at the same time, as in the above sketch. The two works could be constructed simultaneously. They are both very necessary.

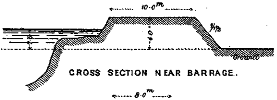
* The Damietta Barrage had originally 71 openings, but 10 were permanently closed by Col. Western.

CHAPTER X.

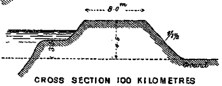
THE NILE IN FLOOD.

The country protected by longitudinal dykes from flood—Sections and type sections—Protective works—Spurs—Training works—Eads on river training—The high flood of 1878—Damage done to the country—Comparison between Rosetta and Damietta branches—Rosetta branch needs widening—High level of water in the Damietta branch—Flood of 1887 in Upper and Lower Egypt—Details of flood protection—Sand bags—"Banquettes"—The wash of the waves—Safety banks—Culverts—Sharp bends—Flood corvée—Experiment to substitute contract for corvée work in flood—The banks of the Po in flood—Selections from Sir Colin Moncrieff's report for 1885—Major Brown's and Mr. Foster's reports of 1893—Flood report of 1894—The undue lengthening out of the Nile flood.

THE Nile, during flood, is considerably higher than the level of the country which is protected by longitudinal embankments. In Upper Egypt a high



CROSS SECTION NEAR BARRAGE.



CROSS SECTION 100 KILOMETRES FROM BARRAGE.



CROSS SECTION NEAR THE SEA

flood rises about 1 metre above the level of the country, and the longitudinal banks along the river being comparatively insignificant are frequently

breached. These breaches are beneficial rather than otherwise, as they allow the high lands near the river's edge to be well washed. The longitudinal sections of the Rosetta and Damietta branches of the river in Lower Egypt show the height of the floods above the level of the country to be in places as much as 3·5 metres. The cross sections of the banks are anything but uniform; they vary from a 10-metre top width near the bifurcation to 2 metres near the sea.

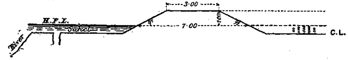
The preceding sections show the Nile banks as they actually are.

The following type sections of banks have been fixed by Major Brown, and are now being worked to:—

TYPE SECTIONS FOR NILE BANKS, LOWER EGYPT.

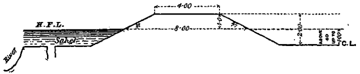
Showing the minimum dimensions that the banks should have under different conditions, to be adopted for all new portions of the Nile banks and whenever any lengths of banks require extensive repairs.

Scale $\frac{1}{100}$.



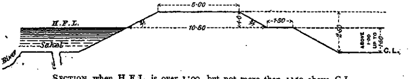
MINIMUM SECTION, to be adopted when high flood level does not exceed 0·50 above country level inside banks.

If the soil is sandy, crest width to be increased to 4 metres.
If the bank is used as a road, the crest width to be 4 metres.

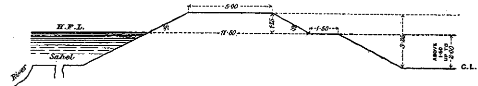


SECTION, when H.F.L. is over 0·50, but not more than 1·00 metre above C.L. inside bank.

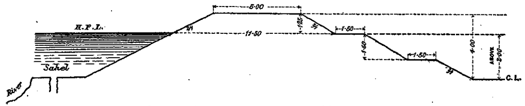
If the bank is used as a road, the crest width to be 5·0 metres.



SECTION, when H.F.L. is over 1·00, but not more than 1·50 above C.L. inside bank.



SECTION, when H.F.L. is over 1·50, but not more than 2·00 above C.L. inside bank.



SECTION, when H.F.L. is over 2·00 above C.L. inside bank.

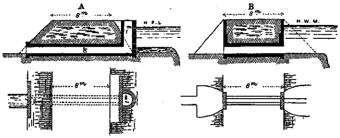
NOTE.—If the infiltration is bad, the lower slopes on the land side to be made $\frac{4}{1}$, or even flatter, as experience may show to be necessary.

If the soil is very sandy, the slopes should be $\frac{5}{1}$, in which case the land side offsets will be omitted.

(N.B.—"Sahel" means berm. C.L. = country level.)

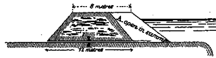
The danger from high floods does not lie so much in the weakness of the banks as in the absence of berm along considerable lengths of the river, and in the presence of numerous culverts in the banks which are always a source of anxiety. With respect to the berm I have always considered that every circle might with advantage annually devote a fixed sum to the throwing back of the bank about 40 metres from the edge of the Nile at all places where spurs are put up. The spurs would stop further encroachments of the river on the particular reaches where they were put up, while a 40-metre berm would ensure the bank between the spurs from being undermined at any stage of the flood. This undermining frequently takes place in winter and early summer, when the Nile is low and the winds strong, although the effects of it are first evident when the Nile comes down in flood. While whole kilometres of bank exist without any berm whatever, the country can never be considered as protected from the dangers of a breach in flood. So far the berms. We now come to the culverts. These culverts are necessary for the summer irrigation of the fields near the Nile. Where they are constructed of good masonry, of sufficient length, and with a well in front, they are not dangerous; but as a rule they are badly built, and not nearly long enough. The following cross sections give (A) a good culvert, and (B) a dangerous one. The dangerous ones, unfortunately, far outnumber

the good ones. Where crossings are needed for watercourses from Persian wheels, it is better not to build any culvert at all, but to fix a galvanised iron pipe (12 metres long, 6 inches diameter, made of $\frac{1}{16}$-inch iron) in two-thirds of the bank, leaving one-third of the bank on the river side open. At the beginning of the flood, when the interior flood canals have

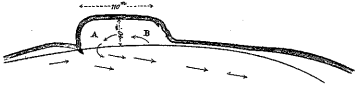


begun to supply water for irrigation, and these culverts are no longer necessary, the opening A can be filled with well-rammed clay, and will give less anxiety and trouble than any other system with which I am acquainted.

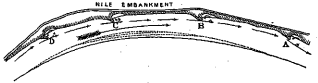
Where there is a considerable berm, or where the velocity of the stream is inconsiderable, no protective or training works are immediately necessary, and none are undertaken. Where, however, the action along the Nile bank



is severe, the banks as a rule are protected either by having stone spread over the slope, or by stone spurs. Where the soil is good, protective works of any kind are effective; where, however, strata of sand are met with, a good deal of skill is necessary to make the protective works effective. The spreading of stone over the slopes is very costly, and needs frequent renewals owing to slips; it is, as a rule, adopted only in front of villages and

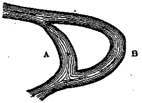


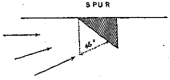
towns, when property is valuable, and it is desirable to preserve the bank in its existing state. At all other places stone spurs are put up. These spurs cause severe action just below themselves, but thoroughly protect the bank. If there is no berm, or the berm is less than 40 metres in width, care should be taken, before putting in the spurs, to throw back the bank. I consider the best alignment to give the new bank is to throw it back as in the preceding sketch. Be the action of the spur never so severe, the water will weary itself in a space 110 × 40 metres in area. By the action of the spurs the thread of the current is thrown away from the bank. Since protection of a bank by this system of spurs concentrates the current, and makes its action



more severe, it is very unadvisable to put in the upstream spurs D, C, B first. The downstream spur at A should first be put in, then B, then C, and so on. By this means the severe current is always kept out in the stream, and never touches the bank except at the spurs.

The size of the spurs and the quantity of material necessary depends entirely on the depth of water and the force of the current, and no rules are worked to. For some spurs 4000 cubic metres are barely sufficient, while others need scarcely 300 cubic metres. The practice followed is to make the spurs at first as small as possible, and then add to them every year. The Nile in passing round the curves has very often a considerable spill channel at A; the larger this channel the less severe is the action at B.



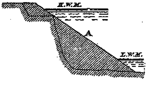


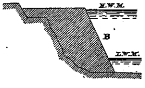
Where there are no spill channels, protective works are doubly necessary. The following rules generally guide the irrigation officers in the construction of spurs :—

1. No spur is to be put in at a right angle to the current, but always at an angle of 135°. As the river rises in flood, the current changes con-

siderably, and if the spur were put at right angles to the cold-weather current, it might even meet the flood at an acute angle.

2. The top of the spur is to be on a gentle incline as at A, and not abrupt as at B. A spur like B produces very severe action just below itself, without any compensating advantage.

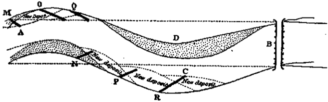




A spur at an angle of 135° and on an incline gives a maximum of efficiency not only for a minimum of money, but also with the least action and consequently with the least danger.

3. The spur is always to be tied well back to the bank, and if there is a berm the spur is to be continued on the berm right up to the Nile bank.

Few attempts have been made at river training in Egypt, but where they have been made they have been very successful. The training works have been ruled by the following principles: (1) That all training works should be put in the shallow water at the tail of the last shoal above the point operated on; thus, in the accompanying sketch, where the river is



wanted to leave the channel A C B and adopt the channel A D B, the first year's spurs are put in at M and N, the next year's at O and P, the third year's at Q and R, and so on. (2) A permeable spur is better than a solid one. Acacia trees anchored in a line are generally employed. Each tree should have an anchor of its own, and be independent of the others. Large trees cost about 3*l.* in position, and the chain and half-ton anchor costs about 3*l.* more. Wherever tried, this system of river training has been most effective.

Among other methods of training, that employed by Mr. Eads on the Mississippi with marked success (the Mississippi has three times the flood

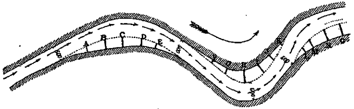
discharge of the Nile), might be adopted with advantage in Egypt. The following is a résumé of Mr. Eads' argument.*

"His plan of jetties or permeable spurs was based upon a knowledge of the fact that the Mississippi river is a transporter of solid material, almost all of which is held in suspension by the mechanical effect of the current; and that the quantity of matter which it is able to carry increases with the square of the velocity. The current of the river is caused by the fall of the water from a higher to a lower level, that is, by the force of gravity. The element which resists the current is the friction of its bed. This friction does not follow the law of solids, but increases or diminishes exactly as the width of bed or wetted perimeter of its cross section is increased or diminished. Hence, if the stream is contracted, where it is too wide, to one half its width, one half of the frictional resistance will be gone, and the current will be more rapid, and therefore more able to carry a larger load of sediment. He then states, 'By some, caving banks are attributed to the direct action of the current against them, by which strata of sand underlying those of clay are supposed to be washed out. This is not correct. If the water be charged with sediment to its normal carrying capacity, it cannot take up more unless the rate of current be increased. Caving banks are caused wholly by the alterations in the velocity of the current. Alterations are inseparable from a curved channel, because the current in the head is usually more rapid than on the point, but if the channel be nearly uniform in width, the caving caused by the curves will be very trifling; and in proof of this, many abrupt curves exist in the lower part of the river, where the whole force of the current has set for years directly against them without any important caving of the banks. The curve at Fort St. Philip is a notable instance, the great difference in the width of the flood-channel constituting the real cause of the destruction and caving of the banks. This tends to great irregularities in the slope of the flood-line, and consequently great changes in current velocity, by which a scouring and depositing action are alternately brought into very active operation. The whole of the river below Red River proves this. Caving banks are much less frequent there than above, because the flood-width of the river is far more uniform. A correction of the *high-water channel*, by reducing it to an approximate uniformity of width, would give uniformity to its slope and current, almost entirely preventing the caving of its banks. By such works the flood can be permanently lowered.' The jetties or spurs were made of piles and willows, and were permeable to the flood."

To treat the Nile on this principle it would be necessary to fix first upon the uniform top width to be adopted. Say 500 metres for the Rosetta branch. By referring to the sketch, it will be seen that the river could be brought to a uniform top width by building light, inexpensive spurs on the sandy shoals. The land between these spurs would rise rapidly and become cultivable. This system of training might have the great advantage of paying its way. It might certainly be adopted above all the ill-placed canal heads, as explained in Chapter XI.

* Taken from the 'Scientific American' Supplement.

There are many places where the reclamation of the sandy shoals would almost pay for the construction of the spurs. This would be in addition to the training of the river.



The Nile is in flood annually during the months of August, September, October and November. The maximum rise at Assuân is 9·10 metres, and at Cairo 8·70. The mean rise is 8 metres at the former and 7 metres at the latter.

Up to a gauge of 7 metres at Cairo there is no danger: beyond that there may be danger, and harm is done both by infiltration, and direct swamping of standing crops on the berms. The ordinary duration of a flood above this level is fifteen days, the maximum duration has been three months.

The two highest floods in this century of which there is any record were in 1874 and 1878. The flood of 1878 was slightly in excess at Assuân. The flood of 1874 was at its highest at Assuân about the 5th of September, when the basins were being filled in Upper Egypt, and irrigation in Lower Egypt brisk everywhere. The river had fallen considerably by the 1st of October when the basins were opened, and consequently it was possible to get through without serious breaches in Lower Egypt, in spite of the Nile banks at the time being in an indifferent condition. The flood of 1878 was very different. The gauge at Assuân was at its highest on the 1st of October when the basins began to be opened or opened themselves, and irrigation in Lower Egypt was slack. The opening of the basins was the signal for an inundation such as Egypt can seldom have seen. The Cairo and Barrage gauges of October, though high, were not nearly so high as they would have been had not the left bank of the Nile breached,* south of Cairo, and a considerable portion of the flood water escaped through the province of Gizeh into the Rosetta Nile, sweeping away the railway bridge near Menashi.

The Rosetta branch rose at Kafr El Zayat 1 metre higher than the level corresponding to the Barrage gauge of the time, but owing to the

* If a year like 1878 were ever to come again, the left bank of the Nile opposite Cairo might be cut with advantage on the 1st of October, in order to save Lower Egypt. The water would flow through the basins and find its way to the Rosetta branch without doing much damage, provided the basin cross banks were also breached.

great capacity of this branch of the Nile, it was able to carry the supply without flooding the whole country. The height of the flood was so extraordinary, that the railway authorities marked the maximum rise against the right abutment of the Kafr Zayat bridge, and cut the figures 1878 against it.

The Damietta Nile did not fare so well. The flood came on at a time when all the canal-heads which take out of this branch had been partially closed, and water was not in much demand. The branch itself, after passing Zifta, has a very contracted channel, and could not carry the supply. The flood rose to nearly the full height of the banks, and eventually breached the left bank of the river, midway between Zifta and Samanûd, and destroyed the standing crops and every village which lay between it and the sea. If the Damietta branch had not been relieved by the breach near Cairo, which discharged into the Rosetta branch, the damage would have been incalculable. As explained in Chapters IV. and V., the Upper Egypt basins must begin to be opened early in October, or they will not dry in time to allow the winter crop to be sown in season.

Before the construction of the Barrages, the maximum discharges of the Rosetta and Damietta branches of the Nile in flood were nearly the same at the head of the Delta proper.* A little lower down, however, the Rosetta branch had considerably more water than the Damietta. About 2 kilometres below the Barrages there was a branch called the Shalakân branch, which flowed from the Damietta into the Rosetta Nile. About 20 kilometres below the Barrage the Bahr Ferouniah took about one-third the total quantity of water out of the Damietta branch and threw it into the Rosetta branch. Both these were closed by Mehemet Ali; and at the same time the Bahrs Sirsâweiah, Baguria, Shebîn, Kadrawîah, Moês, Um Salâma, Mansouriah and Saghêr, were also completely closed, or provided with regulating heads, which very considerably diminished their discharge. Previously they had discharged a very considerable quantity of water, which left the Damietta branch a comparatively insignificant stream. The cross sections of the Damietta branch near the Barrages and at different points down its course in Plate X., show how considerably it is contracted. The cross sections of the Rosetta branch, on the other hand, show that it maintains a uniform section along its entire length.

The closing of the Bahrs Shalakân and Ferouniah has caused the Damietta branch in its upper reaches near the Barrage to suit its section to the contracted section lower down. This it has done by silting up its bed and becoming a broad, shallow stream, which in a very high flood has at its head a considerable increase of discharge for a slight rise of the gauge. This excess discharge in high flood causes great anxiety lower

* *Vide* the notes on Linant Pasha's hydrographic map of Lower Egypt.

down, where the section is contracted. The Karanain Regulator at the head of the old Bahr Shebîn, taking from the Damietta branch below the Bahr Ferouniah, was built in 1842 by Linant Pasha, with its wing wall 60 centimetres higher than any previous flood. By 1870 the Nile had risen 70 centimetres above the wing wall, as measured by Linant Pasha, though Assuân had shown no signs of increase. In 1878, though the Damietta branch was relieved by the Gizeh breach, which discharged into the Rosetta branch, the flood-water surface was 1·50 metre above the wing wall.

From the above considerations it will be evident that the Damietta branch should be trained near its head by long spurs on one bank, so as to contract its channel to half its present size in width, and deepen its bed. This will allow more water to go down in winter and summer, when it is needed, and less in high flood, when it is dangerous. Making the Damietta branch Barrage capable of holding up water in high flood is very desirable. It would ensure the Damietta branch from breaches. But at the same time the Rosetta branch Barrage should have its waterway increased from sixty-one openings to eighty openings. The alternative project is the construction of powerful regulators in the basin banks right through the Geeza Province from Koshêsha to the Rosetta branch. This latter arrangement would permit of the Middle Egypt basin water in a very high flood finding its way direct to the Rosetta branch without endangering either Cairo or the Damietta branch. In case of extreme necessity it would even be possible to relieve the Nile through the Koshêsha escape, using it in the reverse way to what it is used ordinarily. This latter project, if thoroughly carried out, would confer very great benefits on the Geeza basins and minimise the dangers of a very high flood in Lower Egypt.

Besides regulation at the Damietta Barrage, there are two other methods available for reducing supply in this branch during a high flood. One of these is the construction of a second mouth to the Damietta branch from near Ras El Khalîg to the mouth of the Behr Shebîn. It would be necessary to make two good banks in the small patch of cultivated land near the Nile, about 500 metres apart, and let the Nile sweep over the Berea, reclaiming land along its entire length. The other is the construction of a reservoir in the Wâdy Rayân, which will be considered in Chapter XIV. (Reservoirs).

The Nile flood of 1887 was the highest which the country has experienced since 1878, and an account of it will not be without interest. It has been impossible to get any full accounts of former floods.

As far as can be learned, the flood never before attained the level of 8 metres at Cairo without there being disastrous inundations.

In 1861 (the Cairo gauge being 8·16 metres) the right bank of the Damietta branch was breached at Sumbakht, north of Mit Ghamr.

In 1863 (the Cairo gauge being 8·36 metres) the left bank was breached at Talkah, opposite Mansourah, and the same year the right bank of the Rosetta branch was breached at Nadir in Menoufia, opposite Khatatbeh.

In 1865 (the Cairo gauge being 8·65 metres) the right bank of the Damietta branch was breached at Sefer and Mit Damsis, north of Mit Ghamr; the right bank of the Rosetta branch near Dessouk.

In 1869 (the Cairo gauge being 8·67 metres) the left bank of the Damietta branch was breached at Kafr el Hataba, north of Mansourah.

In 1874 (the Cairo gauge being 9·15 metres) the right bank of the Damietta branch was breached at the head of the Bahr Moês, the left bank at Batra, north of Mansourah; the Rosetta branch was breached on its right bank at Dessouk, and again at Gezireh el Fars, 10 miles south of Rosetta. In the 10 kilometres south of Rosetta, this branch of the Nile on its right bank is exceedingly dangerous.

1878 (the Cairo gauge being 9·02 metres) the Nile was breached at the head of the Sharkaweih Canal north of Shubra; the Damietta branch on its right bank at the Bahr Moês head and at Sharabas north of Faraskur; and on its left bank at Mit Badr Halawa between Zifta and Samanûd. The Rosetta branch was breached again at Dessouk, and on the left bank in many places between Khatatbeh and Kafr Zayat, but these latter breaches were insignificant.

The great breach of Mit Badr Halawa has left a marked impression in Egypt. Serious loss of life then occurred. But even more serious was the Nadir breach in September 1863, which occurred early in the flood and could not be closed until the waters subsided; the water moreover travelled down the valley of the Bajûr, where the canals had no high banks to which the people could run for refuge, and where even a greater loss of life occurred than at Mit Badr.

In 1887 the flood rose to 8·40 metres on the Cairo gauge, and no breach occurred throughout Lower Egypt. The result of this was that the flood, having found no vent for escape beyond its banks, assumed graver proportions as it advanced. At the Barrage it was only 26 centimetres below the previous maximum. At Mansourah it was 8 centimetres below the previous maximum. North of Shirbin it was the highest flood on record. Nearly everywhere throughout Lower Egypt it was the right or eastern bank of the river on which there was the heaviest action.

The first high flood after the disastrous one of 1878 was in 1887. The flood of 1887 has been fully described by Sir Colin Scott-Moncrieff in the Report for that year, and from it I take the following selection:—

"The effects of excessive floods on Upper and Lower Egypt are widely different. In Lower Egypt it is necessary to irrigate all lands but to flood none. In Upper Egypt vastly the larger proportion of the land is contained in great basins made on purpose to relieve the flood water, and so long as the embankments which

divide these basins are not topped or carried away, the deeper the water the more the alluvial mud deposited, and the better the winter crops. While there are exceptionally high parts which in an ordinary year are not flooded at all, and remain uncultivated, but in a year like 1887 are as productive as the rest, the injury done in such a year is often more to the villages situated in the basins than to the crops. Every year these villages become islands in shallow lakes, but when the lake deepens discomfort must follow to the islands. The lower houses are swamped, the inhabitants are partially imprisoned and the cattle suffer.

The great basins hardly ever spread to the Nile bank itself. The Nile berm bordering on the river is often too high to be covered by ordinary floods, and generally it is devoted to flood millets. This is either sown when the river is low, and laboriously watered by shadoofs (or in August with the rising flood). The crop ripens during high Nile, and must be protected from inundation. This berm, which left to itself would be the richest in the country, has in many places deteriorated from the effects of over-cropping, and the efforts made to protect it against floodings have also protected it from the wholesome washing and renewal of the muddy Nile flood, so that salt efflorescence has taken place. The principal loss in Upper Egypt was the destruction of the flood millets, but, as Major Ross remarks, in many cases the proprietors looked on the loss with composure, knowing the benefit that their lands would derive from the fresh mud deposit. Moreover, they have seen that many who have protected their crops at great expense now regret having done so, as the filtrations through the loose soil bank of the berm practically destroyed the millets, and so lowered its yield that it did not pay; and now these men find their lands much salter than before.

Writing of the two southern provinces, Keneh and Esneh, Major Ross, Inspector-General of Irrigation, states that the rise of the Nile over that of 1886 was from ·76 to 1 metre; not a very great difference, but enough to inundate the whole of the berms for a period of thirty-six days (from 17th August to 23rd September). The water surface stood from ·40 to ·60 metre above ordinary full supply in the basins. Its slope was uniformly about ·07 metre per kilometre. The depth of water in the basins was from ·70 to 1·20 metre above what is considered full supply; the result of which was that the water of one basin stood back in that to the south of it, and the cross embankments were washed over by the waves and greatly injured. The longitudinal embankments parallel to the river suffered greatly too, and in many places the Nile overflowed them in a shallow film of water. The basin system failed then, and as far as the irrigation of the season was concerned no harm resulted (except to the millet crops), and much good."

In Lower Egypt the whole country is under crop at the time of the flood, and has to be protected. A breach anywhere would be disastrous, while one in the first 100 kilometres might destroy the crops on 300,000 acres. From the first edition, which I wrote immediately after the high flood of 1887, I transcribe exactly what I then stated. The terror reigning over the whole country during a very high flood like 1887 is very striking to any one seeing a flood for the first time. On the settlement of a culvert in the Nile bank near Mit el Kholi, and the consequent first rush of water through the bank, I witnessed a scene which must be common

in Egypt on the occurrence of a serious breach, but which fortunately was rare in 1887. The news that the Nile bank had breached spread fast through the village. The villagers rushed out on to the banks with their children, their cattle, and everything they possessed. The confusion was indescribable. A very narrow bank covered with children, buffalos, poultry and household furniture. The women assembled round the local saint's tomb, beating their breasts, kissing the tomb, and uttering loud shrieks. And every five minutes a gang of men running into the crowd and carrying off something wherewith to close the breach. The fellaheen, meanwhile, were not in the least confused, but in a steady, business-like manner were working at the breach, and closed it in half an hour. I have noticed that while the fellaheen are left to themselves they have a very good idea of what should be done, but when one of the many hundreds of the civil employés on the Nile banks in flood is present, his ignorance and fear seems to take possession of the crowd. These employés are not engineers, and have not the least knowledge of any engineering fact in this world.

One often hears it stated that the best results are obtained from Egyptian subordinates if they are terrorised. I have always, however, found that terrorised subordinates are held back from work by their very fears. During the flood of 1887 I complimented an official on the Nile bank, whose activity was quite disproportionate to his apparent age. He told me that he was a comparatively young man, but that he had had charge of the Nile bank at Mit Badr Halawa when the great breach occured in 1878, and that Ishmael Pasha had telegraphed orders to throw him into the breach. He was given twelve hours' grace, and during the interval his hair had become white: subsequently he was pardoned. The memory of this senseless order had survived and sunk into the minds of other officials. As it happened, during the flood of 1887, a breach very nearly occurred on the opposite bank of the river. Arriving at the spot I saw Mr. Langley, the Assistant Inspector, working hard with a gang of men and fighting the flood. On my asking for the District Engineer, Mr. Langley informed me that he was sitting on the edge of the bank slapping his cheeks like a lunatic and crying out "O my misfortune." He anticipated so severe a punishment that fear had petrified him into stupidity. I remember that my predecessor at the Barrage refused to compliment me on the success of our first year's experiment. The reason he gave was that I had undertaken the experiment with only the prospect before me of a return to India in case of failure; while the prospect before him would have been a permanent sojourn at Fashoda. He added that if I had been in his position I should have done exactly the same as he had done, viz. drawn my salary and run no risks.

The mistake the Government has made in the past has been to economise

in stores and materials, which are most valuable but which have to be paid for. They at the same time have made up for this economy when a really dangerous flood has been on the country, by sending two men on the bank where one has been needed, because the men have not to be paid for. If every second man had been allowed to redeem himself for a trifling sum of money, and the ransom money had been spent in purchasing materials, the engineers would have been far better able to cope with the floods.

During floods the Nile banks are covered with booths at intervals of from 50 to 150 metres, according to the amount of danger incurred. In each booth are two watchmen, while in addition to the above, every really dangerous spot has a special gang of from 50 to 100 men. When the Cairo gauge passes 7·80 metres (24 pics) the number of the corvée is doubled, and the men have to bring with them additional brushwood and Indian-corn stalks as the early protective works are being drowned out, and the Nile is rising against the unprotected parts of the banks.

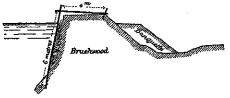
The following memoranda were made during the floods of 1887, 1892 and 1894.

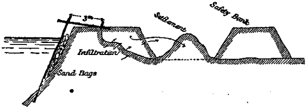
1. *The use of Sand-bags.*—The operations during flood have disclosed the great value of sand-bags. They are easily transported; quickly filled with earth and deposited in place; make a good join with an earthen bank; thrown into deep water, will stand nearly perpendicular if the bank needs to be raised quickly; form a bank practically water-tight; are very cheap compared with stone. Twine and packing-needles should always accompany the bags.

Cotton-seed sacks, 2½ piastres each, are the most economical, and are also easily handled. In using them in running water, a row of stakes should always be driven in, as they prevent the first sacks from rolling; once some fifty sacks are in position the rest do not roll, but stay where thrown. For the efficient use of sand-bags, the banks should everywhere be 1 metre above maximum flood; this permits of taking earth from the top of the bank and quickly filling the sacks and staunching the breach, when there is nothing but water on both sides of the bank; this is a point of very great importance, as at the beginning of a breach time is everything. Sacks should never be filled with sand and left as reserve, as the dampness destroys them; fill them when needed.

2. *Protection of Banks during Flood.*—If a bank is being eaten away in front and there is no infiltration through the bank, a "banquette" is advisable. If, however, the bank has slipped badly on its reverse slope owing to infiltrations, earth should be thrown on the river side if there is any berm; if there is no berm a safety bank should be thrown up, and stakes supporting sand-bags be driven in on the river face. "Banquettes" under these circumstances have done more to endanger the banks than the action of the river itself where the current is very severe. A few

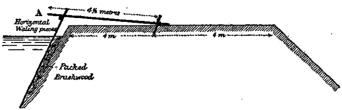
bushy trees thrown into the water, with some sand-bags tied to the branches to weigh them down, and a few boats laden with earth moored





over the trees, protect the bank temporarily, until some more permanent work can be undertaken.

3. *Protection from the Wash of the Waves.*—The ordinary protection of banks by vertical stakes (generally $4\frac{1}{2}$ to 5 metres long) tied or nailed



together, and packed behind with Indian corn stalks and brushwood, is well adapted to save banks from the wash of the waves.

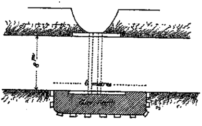
4. *Treatment of Safety Bank.*—No safety bank should be allowed to stand a single year without being subjected to water pressure. High-flood

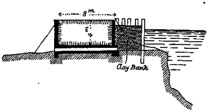


water coming on these new banks for the first time is disastrous. Cuts should be made at A and B before the flood, which may be closed when

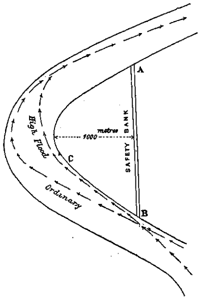
the Nile is very high; they should be opened again when the Nile begins to fall. This not only consolidates the banks, but fills the pits with clay.

5. *Treatment of Culverts.*—All culverts should be provided with clay banks in front of them, as in the following sketch. If the culvert is to be left open, a wooden shoot can be run through the clay bank. The clay bank should keep pace with the rising flood.





These banks cost ·50*l.* per culvert, when very well done, and render the worst culvert harmless. In the dangerous places there are about six culverts per kilometre.



6. *Sharp Bends of the River.*—When the river rises in high flood above its ordinary channel it has a habit of cutting sharp round some corners,

such as C, where the soil is always sandy, and where a breach would soon assume very serious proportions. No bends of this kind should be unprovided with a safety bank, such as A B.

The following estimate was made by me of the cost of protecting the provinces of Menoufia and Garbieh from inundation during the high flood of 1887.

Cost of Nile Protection for 432 kilos., or 1,200,000 acres.

Materials Paid for.	
Sand-bags utilised, 60,000 at £·03	£1,800
Stone " 5,000 at ·50	2,500
Stakes " 55,000 at ·06	3,300
	£7,600
Materials Unpaid for.	
Camel loads of stalk for 42 kilos., 14,000 at £·15 each	£2,100
Total materials	£9,700
Boat Hire and Contingencies.	
15 engineers at £80	£1,200
Corvée, 1,374,079 men at £·03	41,222
Labour and materials, total	£52,122

Therefore: cost of protection per kilometre of bank = 120*l.*, and per acre = ·045*l.*

If the cultivated area of Lower Egypt be taken as 2,750,000 acres, the cost of protecting the country came to 123,750*l.*, of which sum Government paid 26,000*l.* and the fellaheen did work representing 97,750*l.*

Sir Colin Moncrieff, in his note on the Nile flood of 1887, says :—

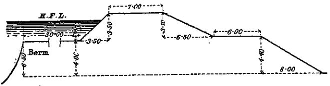
"On the 10th September an important decree was issued that whenever the Nile had reached 24 pics, or 7·80 metres on the Cairo gauge, all persons fit for work, of whatever rank or station, should be liable to give their help in protecting the banks. This law was of some use; but, as heretofore, there is no doubt the burden of protecting the country from inundation fell chiefly on the poor, and the sentiment of 'Noblesse oblige' was conspicuous by its absence among the rich and powerful proprietors."

After the flood of 1887 I obtained the permission of the Government to protect, in 1888, the 50 kilometres of the Rosetta branch north of Kafrzyat by contract and not by corvée labour and materials. The experiment was eminently successful as far as the work of protecting the banks with stakes and brushwood and guarding these was concerned, but as the flood unfortunately turned out to be an insignificant one no conclusions could be made. I may state here that the Nile protection corvée still exists in spite of periodical efforts and experiments to prove the practicability of abolishing

it in ordinary floods. The Irrigation Department might begin to take upon itself the duty of protecting and guarding the banks while the Cairo gauge was below 7·25 metres (23 cubits), and call the corvée out when that figure was passed. The work of staking and protecting with brushwood, and the provision of both stakes and brushwood might certainly be performed by the Government, whether the guardians were paid for or not paid for.

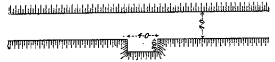
During the winter of 1890–91 I had an opportunity of examining the works in the valley of the Po, in Italy, and extract the following data from my note-book.

"Near Ferrara I saw the Po in very heavy embankment; I measured the section of the bank and found it as follows:—



There was a carriageway on the top of the bank, while the slopes and banquette were beautifully turfed. Nothing short of these splendid banks could give security to the low-lying villages and thickly inhabited country round Ferrara.

At every 100 metres or so along the bank was a platform 4·00 × 3·00 metres, projecting beyond the line of the outer edge of the bank. At each platform was a stone post with a number on it. These platforms were the stations of the guardians who were called out during dangerous floods.



An engineer riding or driving down the bank could note in an instant the numbers of the guardians who were absent from their posts, and report the matter to the proper authorities. It struck me that we might imitate the Italians in this matter with great advantage.

At the Viloresi Canal head, on the Ticino, near Milan, I noticed that in an exceedingly swift velocity on a coarse shingle bed the engineers had trained the river by means of boulders packed inside galvanised wire nets of a cylindrical form, each 3 metres long by 2 metres diameter. The meshes were 16 centimetres square, and the thickness of the wire 3 millimetres. Each wire net weighed 35 kilogrammes, and including cost of filling with stone and putting into place, cost 1*l.* While watching the operation it struck me that these wire nets were far superior and infinitely more suitable for lowering stones down a dangerous slope in flood time, or closing a breach, than the ordinary palm fibre nets, or 'chinfs,' which have no power of resistance."

I shall complete this chapter with selections from the Irrigation Department Reports for the different years. The first is from the Report of Sir Colin Scott-Moncrieff for 1885:—

"In 1885 there was spent in protection against the Nile inundation the sum of 61,553*l.* In 1884 it amounted to 58,000*l.*

Some protection was found necessary opposite the town of Luxor in the province of Keneh, and a groyne was thrown out which will I think prevent further mischief.

In the Girgeh Province protective measures were required at the heads of inundation canals, and amounting to 1289*l.*

At Mungabad, in the province of Asssiout, dangerous action is still going on. Captain Brown expended 1006*l.* there on groynes, containing about 3700 cubic metres of stone. At Nazali 2900 cubic metres of stone groynes were made at a cost of 486*l.* Captain Brown reports that this place is less dangerous than it was.

Some protection was found necessary to the left bank of the Ibrahimieh Canal just where it leaves the river. On this there was an outlay of 811*l.* At Wasta there was an expenditure of 635*l.* on a groyne of 4130 cubic metres. This work was ineffectual, and extensive operations have been found necessary there this year.

Altogether Captain Brown spent 9395*l.* on protective works.

In Giseh, groynes were built at Korimat, Nazlet Alian, Nazlet-el-Tabut, Badrashein and the head of the island of Roda. These amounted altogether to 7650 cubic metres.

In Lower Egypt Mr. Willcocks tried the experiment of substituting roughly made but hard bricks for the stone used in groynes. The object was economy, and it was certainly attained comparing the price of an equal volume of bricks with stones. But as about one-third of the latter returns to Government in the shape of heavy bridge tolls, the gain to the Treasury is not very much. There is anyhow a relief to the P. W. Budget.

Mr. Willcocks spent in Menoufieh and Garbieh altogether 12,003*l.* on river groynes, etc., including an outlay of 3807*l.* on those directly above the Barrage, and on very numerous protective works on both branches of the river. The quantity of stone and brick employed came altogether to 35,426 cubic metres. Less was done in the Eastern Provinces, but much stone was collected for future use. In Behera, Mr. Foster constructed ten different groynes on the river at an outlay of 6274*l.*

During the summer of 1885, Mr. Willcocks raised an alarm on account of the danger that might befall the embankments of the Nile owing to the numerous faulty culverts with which they were pierced. Cultivators were in the habit of erecting water wheels where they pleased, and building the most flimsy culverts to pass their water through the embankments. It was a well received belief that all the breaches that had occurred to the Nile embankments could be traced to the failure of culverts. Orders were thereupon issued on 29th July, 1885, controlling the construction of all such culverts in future, laying down rules for the circumstances in which they might be built, and ordering that all such as might not be approved in construction before 1st May, 1886, should be removed entirely. It is to be hoped that these instructions will bear good fruit, and not be neglected, like so many good circulars that have been issued before now.

On the 6th August was issued an important decree laying down rules for the

Corvée to be employed on guarding the Nile embankments. In each province an Agricultural Council is to be held every year on the 15th July to determine on the Corvée required for the approaching Nile flood. The numbers to be taken from each village are to be divided into two divisions, one of which will commence their work on 1st August and remain out until the floods are passed. The other division will form a reserve and not be called out until 1st September, when the high water is approaching. Punishments are fixed for those refusing to do their share of the work. The chief use of this decree is, in my opinion, that it will check the indiscriminate way in which it has been the custom to force quite an unnecessary number of watchmen to guard the river, for quite an unnecessary length of time, experience showing that little danger is to be anticipated before 1st September."

The next two selections are from the pens of Major Brown and Mr. Foster respectively, and have been taken from the Report of 1893. It will be seen that wherever an experiment has been made to substitute paid or contract labour for corvée labour, it has given eminent satisfaction. Major Brown certainly writes with conviction :—

"In the Fifth Circle and Girga Directorate the service of Nile guardians was discreditably supervised. The Mudiriyah officials care nothing if half the banks are eaten away by the waves, as they are not responsible for the repairs, and even if there is a breach they lay the blame on the defenceless gaffirs, who are sometimes thereupon punished. For ten years I have been trying to effect some improvement in the manner of protecting basin and Nile banks during flood, and I confess to having completely failed. The officials who, under the present unsatisfactory system, have the Nile watchmen under their control, are not under the orders of the Irrigation officer, and their own chiefs do not take any steps to see that they carry out their duties on the flood banks, nor does he hold them responsible for their neglect to do so, unless an extraordinarily high Nile alarms the higher officials in the Ministries, and stringent circulars are issued. Without the application of this special stimulus, these duties are neglected by the local authorities, and the necessity of issuing circulars during times of emergency witnesses to the truth of this statement. The sooner the Nile Corvée is paid for, and the Irrigation Department made solely responsible for the Nile protection of the banks, as it is already responsible for their repairs, the sooner will the work stand a chance of being done satisfactorily.

In 1893 the experiment of paying for Nile protection was tried in Manfalut District, under the control of the Irrigation officers, and in this district alone, of all the districts in Upper Egypt, was the Nile protection satisfactorily done. As the Nile levels were below those of an average flood, the experiment had not the value that it would have had if the flood had been a good one. Nevertheless it taught something, and confirmed me in my opinions just expressed. In the Manfalut District there are 159 kilometres of bank which have to be protected. The expenditure was 1560*l.*, of which 320*l.* was for charges under the head of supervising staff. The men were paid as daily labourers directly by the Government officer. The large supervising establishment that such a system requires, forbids the extension of it to larger areas than a district, and, if the Nile Corvée is to be abolished in Upper Egypt, it must in my opinion be brought about by introducing contract

work, to which I consider there are not the same objections in Upper Egypt as are urged against it in Lower Egypt."

"For some time past there has been a universal desire to introduce the system of paying the men called out to guard the Nile banks.

To frame an accurate estimate of what the cost would be was not possible, the available data being insufficient.

It was well known that the nominal numbers called out were far in excess of requirements. A smaller number, if properly supervised, would do as good, if not better, work.

The number of men required, and consequently the amount involved, would necessarily vary with the magnitude of the flood.

In order to get some idea of what the cost for the whole of Egypt would be, it was suggested, and the approval of Government received, to make an experiment on a small scale.

Two markazes, or districts, in the Delta nearest the sea were selected, in which the experiment was to be tried. These were Markaz Atfeh in the Beheřa Province (Third Circle), and Markaz Belcas in the Garbieh Province (Second Circle). These localities were chosen because the hardship of guarding them is greater than anywhere else. This is due to the necessity for bringing men from long distances, because the adjacent villages, being few in number and small as regards population, are unable to provide men in sufficient numbers to effectively guard the banks.

Besides this, some of the most dangerous erosions are to be found in these distant parts. These reaches were therefore considered the best to experiment on.

It was decided to pay each man employed at the rate of 2 piastres per day, and the sheikhs, who always accompany gangs from each village, at the rate of 4 piastres per day.

All materials, such as stalks, grass, nails, etc., which it was the custom for the inhabitants to provide at their own cost, were to be paid for.

As far as it went the experiment proved a great success, but owing to the flood having been a low one the experience gained has been limited, and the data for making an accurate estimate not yet procured.

It is sufficient here merely to give an abstract of the number of men employed, materials purchased and cost. The following table gives these details:—

Markaz.	Length of Bank	Labour				Total Cost of Labour	Cost of Materials	—	Total Cost	Average Cost per kilo.
		Sheiks		Men						
		Number	Cost	Number	Cost					
Second Circle:			£		£	£	£		£	£
Belcas. . .	66	1194	48	18568	371	419	90	14	523	7·92
Third Circle:										
Atfeh . . .	45	1970	79	30491	610	689	143	19	851	18·91
Totals . .	111	3164	127	49059	981	1108	233	33	1374	12·38

I must, however, add that the success was due to the pains taken by Mr. Joseph and Ismail Bey Sirry, inspectors of the two Circles, and of Mr. Langley, who was deputed by the latter inspector to personally supervise the experiment in the Belcas Markaz, and to the steady hard work of the subordinate engineers employed."

The next selections are from the Reports of Sir William Garstin and Major Brown for 1894, the last of the high floods we have had. It will be noticed that the special expenditure has considerably diminished, owing to the additional stability imparted to the banks by the yearly protective works. No money in this country is better spent than that devoted to the execution of works which protect old well-placed banks. Every old bank with a substantial berm in front of it, which has stood a number of high floods, is a valuable asset, and every effort should be made by the country to conserve these berms and not allow the river to come up against the banks. It will also be noted that the duration of the floods is being gradually drawn out in a way which, in the opinion of many, exposes the country by the long-continued strain on the banks to greater dangers than those incurred by higher floods of shorter duration. Now, even in 1887, when scores of kilometres of new banks thrown up after the disasters of 1878 faced their first high flood, the Cairo gauge rose to 8·40 metres (25p·2k) without the occurrence of a single breach. That point once gained, the next high flood might have been allowed to rise to 8·50, and the next to 8·60 and so on, gradually, so that when a flood like 1874 or 1878 came again, and Cairo rose to 9·00 or 9·20 in spite of the engineers, the country would not be made to incur the very gravest dangers by having to face suddenly a flood of such proportions with banks untried and untested. The Department, unfortunately in my opinion, chose 8·10 metres (24p·12k) as the maximum to be worked to, and has thus been forced to draw out the floods into November, in a way which is not only harmful to agriculture but to the health of the country, by the long-continued infiltrations and stagnant pools behind the Nile banks. The key of the whole situation is the date of the opening of the Delgawi escape. In a high flood the opening of this escape on the 1st of October, would produce the maximum on the 12th of October, and the river would then fall rapidly. In the interests of the country, and as an insurance against the terrible calamity of a possible inundation, the Caisse of the Public Department might be called upon to supply 250,000*l.* for putting the country out of danger in a high flood, if it is really considered unsafe to open Delgawi on the 1st of October without additional protective works in a year of high flood. Sir William Garstin writes :—

"The flood rose early and remained at an abnormal height to an exceptionally late period of the year. It remained above the dangerous height of 24 cubits at Roda for forty-two days, and the highest level reached was within 5 kirats of that attained by the great flood of 1892. As far as Lower Egypt is concerned, the flood

of 1894 may be classed with the four great floods of the last twenty years, and owing to the maximum level not having been attained at Cairo until the 27th October (or sixteen days later than in any of the four preceding great floods), the banks were tested to an exceptionally severe degree. It is satisfactory to record that this flood passed off without doing any damage beyond the infiltration which must of necessity be caused whenever the level of the river passes a certain height at Cairo. This result is due to the precautions taken by Mr. Foster and Major Brown for protecting the banks and for controlling the discharge of the Upper Egypt Basins.

The special flood expenditure in 1894 compares very favourably with that incurred in 1887 and 1892. The following is the comparison:—

1887	1892	1894
£44,673	£23,049	£7,634

Deducting from the above the value of useful material available after the flood, the above figures become:—

1887	1892	1894
£27,520	£11,681	£6,142

In the number of watchmen called out in 1894 to guard the Nile banks during the period of the flood, we also find a satisfactory diminution as compared with the years 1887 and 1892.

The figures are, taking the unit of 100 days:—

Year	Locality	Number of Men per 100 Days	Total
1887	Upper Egypt	36,371	87,120
"	Lower Egypt	50,744	
1892	Upper Egypt	35,726	84,391
"	Lower Egypt	48,665	
1894	Upper Egypt	33,223	60,017
"	Lower Egypt	26,794	

It will be observed that the diminution of the numbers has been much more marked in Lower than in Upper Egypt. The reason is that in the latter the greater proportion of the watchmen are employed upon the basin banks, which are to a large extent independent of the height of the river."

"*Flood Season, Upper Egypt.*—The following table will show that, as regards the maximum levels reached at different points, the flood of 1894 was, at points south of Asyût, from 30 to 40 centimetres lower than the flood of 1892, and from 30 to 50 centimetres lower than the flood of 1887. At Asyût the 1894 flood was 27 centimetres below that of 1892, and 13 above that of 1887. At Wastah the 1894 flood was 23 centimetres below that of 1892 and 25 above that of 1887. At Rodah (Cairo), the 1894 flood was 11 centimetres lower than the other two floods.

The lowering of the flood levels south of Asyût, between 1887 and 1892, was probably due to the enlargement of the basin feeders, in consequence of which

more of the flood water passed into the basins, and the flood in the Nile channel itself was lowered. From the same cause, also, the basins become more completely full before the time for their discharge, so that we find the reverse effect taking place on the Nile levels at the time of the basin discharge at and below Asyût.

	1887	1892	1894
Assuan . . R.L. in metres	93·81	93·88	93·70
Armant	78·99	79·08	78·66
Suhag canal head . . .	62·22	62·04	61·67
Asyût	52·86	53·26	52·99
Wastah	26·74	27·22	26·99
Rodah (Cairo)	20·63	20·63	20·52

An important point to note is that the maxima were reached at Asyût and Cairo on the dates given below :—

—	1887	1892	1894
Asyût .	17th September	27th September	11th October
Cairo .	25th „	2nd October	27th „
Intervals	8 days	5 days	16 days

Thus, in 1894, the maximum was reached 32 days later than it was in 1887 and 25 days later than in 1894. It was this feature of the flood of 1894 that made it so formidable in the Fourth Circle and Lower Egypt. Above Asyût the 1894 flood was not, in the river itself, a formidable one, and gave little trouble; but the river levels of the month of October below Asyût were in excess of the flood of 1887, and were sufficiently high and prolonged for the flood to be classed among the formidable ones. The strain in the Fifth Circle and Girga Directorate was felt in the basins, which filled rapidly at an early date, and consequently required attention for an unusually long period.

High floods, such as those of 1887, 1892 and 1894, leave a large deposit of content behind them in Upper Egypt, and especially do they do so now that accidents have become so rare as compared with former floods."

"*Flood Season, Lower Egypt.*—As the early rise of the Nile at Assuan to high levels in August gave rise to apprehension, Mr. Foster arranged that Mr. Wilson should be in charge of the operations for flood defence on the Damietta Branch, while Mr. Willcocks should supervise the Rosetta Branch and the river banks and protective works in Ghizeh Province. This arrangement had excellent results and no accidents occurred, though many threatened to occur. Most of the difficulties of preserving the Nile banks from breaching arose from many of the spurs not having been properly tied back to the bank behind them in such a way as to prevent the current getting in between them and the bank which they are intended to protect. The point that gave most trouble was Kafr Rifai, south of Mazghounah, in the Ghizeh Province.

As the river at the Barrage rose above the top of the lock walls, it was found necessary, for the sake of navigation, to indicate their position by walls of dry rubble formed along their crests.

In high Niles the absence of a head regulator to the Khatatbeh intake causes trouble, as the discharge, which, for want of it, is allowed to reach Kafr Bulin, is in excess of the requirements of the canals below the regulators there, even after it has been reduced by the full power of the Kafr Bulin escape. To relieve the over-full canal a cut was made on to the river at el Kam on the 24th September, which succeeded in bringing down the water level at Kafr Bulin to R.L. 10·50, the theoretical H.W.L. But when the Nile rose further in consequence of the basin discharge, the W.L. at Kafr Bulin increased to R.L. 10·95, and another cut had to be made on the 26th October at Tyrieh, which succeeded in bringing the level down to the extent desired. These two cuts were again closed on the 10th and 12th November."

The final selection is from Sir William Garstin's Report for 1897. If we examine the table at the end, we find that the Nile corvée during the last ten years has represented 4,400,000 days labour per annum. This, at 3 piastres per man, means a sum of 132,000*l.* per annum. From careful experiments and calculations made during successive floods, I estimate that the brushwood and corn-stalks provided by the corvée cost 50*l.* per kilometre, and that 1 kilometre in 10 on an average needs such protection. If we take the Nile bank needing protection at 2300 kilometres, and the basin banks similarly situated at 1400 kilometres, we shall find that the brushwood and corn-stalk provision will come to 11,500*l.* for the Nile bank and 7000*l.* for the basins, or 18,500*l.* in all. The Nile bank protection has therefore cost the country about 150,000*l.* per annum in men and materials, towards which the State has contributed nothing. Now, if we eliminate the extra corvée needed for Nile protection after the Cairo gauge has passed 7·25 metres (23 pics) we shall find that 2,000,000 days' labour is ample provision for a single year. This means an expenditure of 60,000*l.* If to this we add 18,500*l.* for materials, we arrive at a total of 78,500*l.* per annum, which the Caisse of the Public Department might easily provide; and, in case of their refusing to do so, a tax of 1¾ piastres per acre on 4,700,000 acres would be gladly paid by the country to be saved the worry and annoyance of guarding the banks at times when the flood is below 7·25 metres and there is no danger whatever. When the flood is over 7·25 metres possibly, and certainly when it is over 7·80 metres (24 pics), there will be no question for many years of the necessity of calling out the corvée to guard the banks.

Now that the Soudan has been retaken, and the Government been put in possession of the means of obtaining the most valuable information about the floods long before they reach Egypt, it would be an act of justice for the Government to order this partial abolition of the Nile flood corvée. This partial abolition might be considered as a reward for the splendid manner in which the fellaheen soldiers, working exactly like a corvée, constructed the Soudan railway without any pay or remuneration whatever, and so facilitated the reconquest of the Soudan as much as all the other

factors put together. They saved the country millions of money and thousands of lives. Sir W. Garstin writes :—

"A most satisfactory reduction has been made in the number of watchmen called out to guard the banks in 1897, the total being less than half that for the year previous, which again was the lowest on record.

It is true that this reduction was rendered possible by the low height to which the flood rose in 1897, and the consequent diminution in the danger to the banks. Allowing this fact, if the year 1897 be compared with previous years of low flood, such as 1888 and 1893, the result is still in favour of last year.

The figures for 1897 are as follows :—

Upper Egypt	= 8,398	men for 100 days.
Lower Egypt	= 2,432	„ „
Total	10,830	

Comparing this with the similar year 1893 we get :—

1893. . . . . =32,752 men for 100 days.

Thus last year's total is about one-third of that for 1893.

I think the Inspectors-General and the Inspectors of Irrigation have good reasons to plume themselves upon the success of their efforts for reduction of the Nile corvée. The labour which has been bestowed in past years upon the strengthening of the Nile banks and the repairs to the Nile culverts, has undoubtedly largely assisted the attainment of the satisfactory results recorded for 1897. Better arrangements for the checking of the numbers, and for preventing men from being called out to guard portions of the banks which are safe from danger, have now been made. The Mudirs and the Inspectors of Irrigation have worked cordially together to attain this end, and I hope that even the low figures given for last year may be gradually reduced.

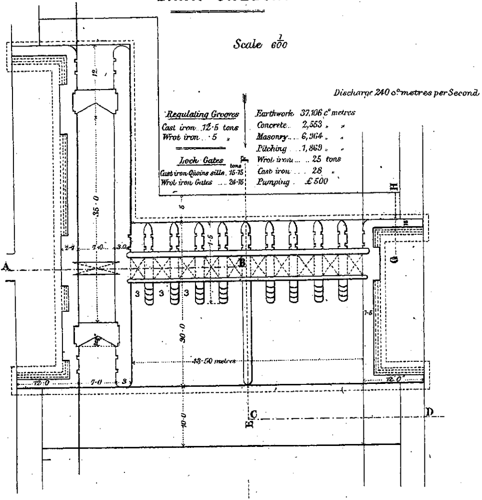
Of course, whenever a high flood occurs, there must be an increase in the numbers. Such an event is a danger to the country, and precautions must be taken to prevent a catastrophe. Even in such a case, however, the figures will never again I hope rise to those recorded for former floods.

The following are the figures for the last ten years :—

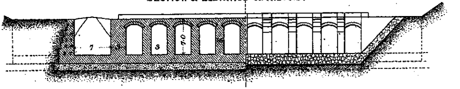
Years	Number of Men for 100 days	Character of Flood
1888	58,708	Very low
1889	49,904	Medium
1890	48,488	„
1891	44,962	„
1892	84,391	Very high
1893	32,752	Low
1894	49,448	High
1895	36,982	Medium
1896	25,794	„
1897	11,069	Low

MELÍG REGULATOR.
ON
BAHR CHEBIN.

Scale 1/600

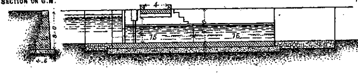


SECTION & ELEVATION ON A.B.C.D.



SECTION ON G.H.

SECTION & ELEVATION ON E.F.



Reference.

Masonry Concrete Pitching

CHAPTER XI.

ENGINEERING DETAILS.

Regulators—Typical old regulators—Melig—Bahr Saidi head—Floor curtains—Unwatering—Well foundations—Best form of foundation—Up and down stream aprons—Systems of regulation—Vertical needles—Horizontal sleepers—Iron gates—Gangara—Rayah Tewfiki head—Koshêsha—Rashwania Canal Regulator—Suresnes—Pont aux Anglais—Poses—Belleek—Manchester Ship Canal regulators—Dowleishweran—Bobherlanka—Narora—Silt deposits in canals—Excessive velocity—Checked velocity—Expedients for stopping deposits—Naggar and Nenaiah Canal heads—River training needed near canal heads—Sohagia and Baguria—Ramadi and Girgawiah—Ibrahimia and Rayah Menufia—Silting up of tail reaches of canals and escapes—Navigation—Prohibitive tolls—Dimensions of boats, etc.—Lock gates—Aqueducts and cross drainage works—Iron pipes—Discharge of the Nile—Colonel Western—Harlâcher—Notes on dredging—Specifications—Lock gates—Well sinking—Masonry works—Dredging—Rates of work—Mr. Wilson's Report on works for 1897—Major Brown's Report for 1897.

THIS chapter will be devoted to a consideration of the details of the irrigation works mentioned in the preceding chapters.

Regulators.—Masonry works for regulating the supplies in canals at their heads or at any part of their course, and similar works in the banks of the basins for regulating the supplies from one basin to the other or for escaping the water from the basins into the Nile, all come under this category. Nearly all the works have their floors flush with the beds of the canals. This necessarily follows from the fact that the perennial canals often carry in summer but a fraction of the supply they carry in flood, while the flood canals have the same vicissitudes between a year of high flood and a year of drought. Plate XXVII. gives a plan of the Melig regulator on the Bahr Shebîn, founded on a clay soil and completed in 1887. The floor is flush with the bed of the canal; it has a thickness of 2 metres and is designed to hold up a head of 3·00 metres of water. The foundations of the floors and wings are all taken down to the same level.

The following table gives details of some typical old Egyptian regulators.

The old regulating heads of the canals used to be retired from 100 to 300 metres from the edge of the Nile. This meant heavy silt clearances upstream of the heads if the regulators were much used in flood, but it ensured the construction of the work on fairly good soil. Recent practice has consisted in taking the head regulators well forward and protecting them with pitching. Recent foreshores should, however, be avoided, as they consist at times of a most unreliable soil. The Bahr Saidi Head

TABLE I.—DETAILS OF OLD EGYPTIAN REGULATORS (IN METRES).

Name of Regulator	No. of Openings	Width of Openings		Maximum Depth of Water on Floor	Maximum Head of Water	Thickness of Floor	Height of Wing Walls	Height of Roadway above Floor	Length of Floor	Length of Arch	Length of Floor Upstream of Arch	Length of Floor Downstream of Arch	Thickness of Wing Wall at Top	Length of Downstream Wing Wall Return
		Central	Side											
Nashart . . .	5	3·68	3·00	6·00	3·50	2·50	7·15	9·10	34·50	7·80	5·40	21·30	2·20	19·50
Rahbain . . .	9	5·10	2·20	7·80	2·50	3·00	8·10	11·00	36·20	12·70	4·60	18·90	1·50	17·50
Tanta . . .	2	3·20	3·20	4·80	3·00	2·00	5·00	7·40	22·40	5·60	9·40	9·20	1·20	11·20
Ganzúr . . .	3	3·50	2·50	6·50	2·50	1·70	8·00	11·00	34·80	9·80	5·70	19·35	2·00	11·00
Birshams South . .	3	4·50	2·40	9·0	2·50	1·50	8·60	11·00	24·10	9·00	5·40	9·70	2·30	11·00
Baguriâ . . .	5	4·00	3·00	8·0	3·00	(?)	8·10	10·20	32·10	9·30	4·00	18·80 (broken)	1·75	10·70
Shubrabâs . . .	5	4·00	3·00	7·0	3·0	(?)	5·70	8·20	20·70	6·70	5·00	9·00	3·10	7·35
Birshams North . .	7	5·50	2·10	9·0	3·0	(?)	8·30	12·00	32·80	10·80	4·80	17·20	2·35	11·90
Nenaiah Head . .	2	3·00	3·00	7·5	3·0	1·80	7·80	10·80	33·80	9·21	6·00	18·60	2·00	11·80
Khadarawiah . .	3	3·10	2·35	9·0	3·0	2·0	7·50	9·70	24·40	7·90	2·60	14·00	1·60	10·90
Basiun . . .	8	3·00	3·0	6·0	2·0	2·2	6·4	8·4	36·5	5·5	8·0	23·0	1·80	9·00
Nenaiah Reg. . .	10	4·0	4·0	8·0	1·0	2·0	7·95	11·05	36·5	6·8	10·45	19·25	2·0	15·60
Karanain . . .	10	5·0	5·0	9·0	3·0	3·0	8·6	10·28	34·7	6·0	7·4	20·5	1·0	19·00
Santa	11	5·16	2·28	9·0	3·0	2·0	8·5	11·50	40·25	6·85	12·40	21·00	1·20	—
Deméra . . .	7	4·67	2·08	8·0	3·0	2·0	7·25	10·00	37·00	5·00	11·00	21·00	1·70	—

in Garbieh is an example of a work taken too far forward and constructed on a soil with but little consistency.

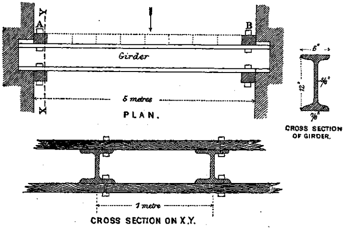
In regulating works we often see designs in which the floor has up and downstream curtains taken a metre or so below the general level of the floor. If the soil is stiff clay or dry sand, where the foundations can be got in without pumping, the curtains are well placed. If, however, the foundation is on sand or silt below spring level, and pumping is required to put in the curtains in the dry and the spring level is temporarily lowered below the general foundation level, it will be found that the superstructure will have unsightly cracks when the works are completed and put to use. In such cases the curtains should be excavated with the water standing in them and formed of cement concrete tipped into the water. It is better, however, to have recourse to iron piles or well foundations. Whatever is done the pumping should on no account be taken below the general foundation level. During the repairs of a massive regulator in Egypt which had a deep pool scoured out downstream of its floor, the unwatering was by an oversight continued until the level of the water in the pool fell below the foundation level, and the whole regulator slid into the pool and became a complete wreck. Infinite damage is occasionally done to works whose floors are carelessly laid dry during the repairing season. Pumping on such occasions should be undertaken with the utmost caution. How often has a serious crack been seen to extend down the whole length of a lock floor when the weight of the water has been suddenly taken off the floor and the original design has not provided for wells or extra support of some kind for the heavy lock walls. A perfect work built on sand saturated with water should, I think, provide for wells descending below the general foundation level under the abutments, the piers and especially the locks walls. Such wells are often omitted for economy of money or of time, but it is a false economy. Where works designed with proper well foundations have not proved a success, it has generally been due to pumping carried down to excessively low levels to expedite well sinking, and which has deranged the soil below the general foundation level. Where compressed air is employed such risks are saved, but with wells sunk in the ordinary way with dredgers there need be no apprehension if pumping is not carried too low. Well sinking by dredgers on the most scientific principles has been carried to a very high pitch of excellence at the Glasgow docks.

The question of the best form of foundation for a regulating work on sand is one of the very greatest importance. Opinions are by no means uniform on the subject, but certain principles are accepted by those most competent to form an opinion. A head of 4 metres of water is the maximum which should be placed on any work built on sand or silt. A mass of loose stone pitching traversed longitudinally by insignificant masonry walls, as at the Okla dam (on Plate XXI.), is quite capable of holding up

to 3 metres of water, and becomes staunched by the mud held in suspension during flood, provided the submerged weight of the mass of loose stone bears to the water pressure a proportion of 40 or 50 to 1. In regulating works which have masonry floors, it is preferable to extend the floor on the upstream side of the line of regulating gates than to extend it considerably on the downstream side after a distance of from 10 to 20 metres, depending on the importance of the work. On the downstream side there should be provided an apron of loose pitching which the water cannot displace, and which can give a vent to clean springs throwing water which contains no deposit. Staunching this downstream pitching with mortar and making it water-tight can only be compared to the act of making the downstream slope of an earthen dam water-tight. Make the upstream side as water-tight as possible and have the downstream talus as permeable as possible.

The *system of regulation* in ordinary use in Egypt before 1885 was that of *vertical needles*, resting against horizontal girders or beams; the horizontals were fixed to a frame, which moved in the grooves. The accompanying sketch shows the four vertical timbers (generally 25 centimetres × 15 centimetres in section), to which were bolted the iron horizontals. The vertical needles were lowered between A and B, and rested against the girders. There were two great advantages in this system.

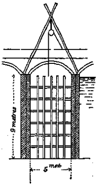
1. The vertical needles divided the falling water into a number of threads and so completely broke its force. They thus protected the floor and the

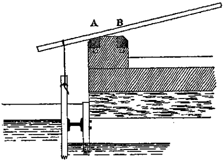


pitching, and did away with the necessity for cisterns or solid stone floors. An ordinary brick floor, without any cistern, easily stood the shock of from 10 to 15 cubic metres of water per second per metre run of floor falling

2 metres, provided the verticals were carefully spaced, and driven down to the floor.

2. This system could be used in any depth of water. It answered as well in 9 metres of water as in 3 metres. A pair of sheer legs was erected over the opening, and the verticals were lifted by a 3½-inch rope, working over pulley-blocks, and lowered in front of the horizontals; the water drove the verticals against the horizontal frame. When a sufficient number of verticals had been thus lowered, a wooden monkey was attached to the rope passing through the upper pulley-block, and the verticals driven home, and then spaced. For lifting the verticals, if the head of water was over 1 metre, the most ready method was to attach a chain to the head of the vertical tie, the other end of the chain to a loose timber lying on the bridge, and, making use of the parapet as a fulcrum, raise the vertical by leverage. The final operation of lifting the vertical out of the water, and laying it on the bridge was performed by the sheer legs. This was the system of regulation practised in Egypt from time immemorial. Either iron girders or oak beams were used for horizontals. For the verticals, pine-wood (Kamera) was preferred to fir (Bartoum). The upstream parapet of the bridge had two wooden beams running along the edges (as at A and B, in section), to protect the parapet from the rough handling it





received. Where stone was cheap a course of ashlar replaced the wooden beams. The needles used in Egypt had originally far too large a section, and were in consequence unwieldy. For depths of 5 metres and under, a section of 10 centimetres × 10 centimetres was found to suffice. The disadvantages of this system were :—

1st. The necessity of having a large gang of men to work the needles; and

2nd. The difficulty of making a water-tight closure.

The first disadvantage was not felt during the flood, since there were always corvée labourers available; nor was the second of much consequence in flood, since no water-tight joints were really needed at that time of the year. In summer, however, no corvée was latterly available for this kind of work, while water-tight closures were frequently needed, and consequently some change became necessary. Advantage was in places taken of the fact that nine out of ten of the regulators had their floors much lower than was necessary, to raise the floors to the highest level possible with efficiency by means of masonry walls. The regulation by means of vertical needles was carried on above them. The water was broken up into threads as before, while the length of the needles was reduced by two or three metres.

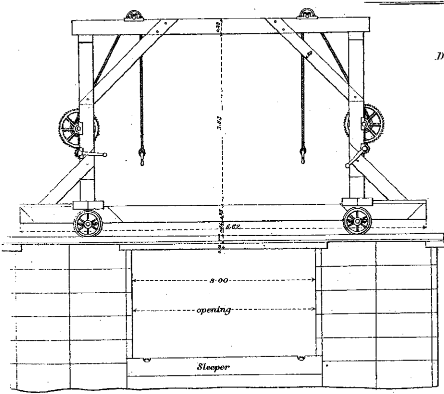
Since 1886 for depths of water of 5 metres and under, movable horizontal sleepers have been introduced and gradually have displaced the needles. They make a water-tight joint and need a much smaller establishment. They are manipulated with a head of water of as much as 3 metres. Of course the main difficulty lies in lowering the sleepers through so great a depth of water and against so great a head, and this is often not successfully accomplished. Lowering and raising the horizontal sleepers is performed very much as it is on the canals in Upper India, where the depth of water never exceeds 3 metres. Where the regulators are of any magnitude the horizontal sleepers are raised and lowered by means of a carriage travelling on rails, of which the drawing on Plate XXVIII., taken from M. Barois' 'l'Irrigation en Égypte' gives a very good idea. One very serious disadvantage connected with horizontal timbers for regulation is the fact that, except at the head, the lower timbers are scarcely ever moved, and the water surface is, in consequence, maintained throughout the year at a higher level than is actually necessary. This high-level water injures the land by percolation.

For the new regulators on the Rayah Tewfiki, Colonel Western and Mr. Reid have constructed wrought *iron gates*, worked by travelling crabs. These gates have the future before them. Plate XXIX. gives details of one of these gates. Each opening is provided with two gates, sliding in separate iron grooves, which together from a double groove. These gates are easily worked, and can make a water-tight joint; the openings are 5 metres wide in every case. At the Barrage, where the openings are 5 metres wide, the new gates are provided with two rollers on each side, in order to lessen the friction between the gate and the iron groove. The gates descend by their own weight.

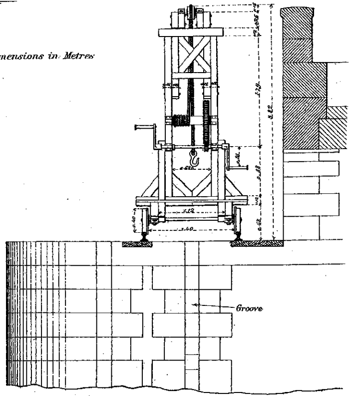
In order to give a good example of recent Egyptian practice in the

TRAVELLING CARRIAGE FOR HORIZONTAL SLEEPERS.

FRONT ELEVATION.



SIDE ELEVATION & SECTION.

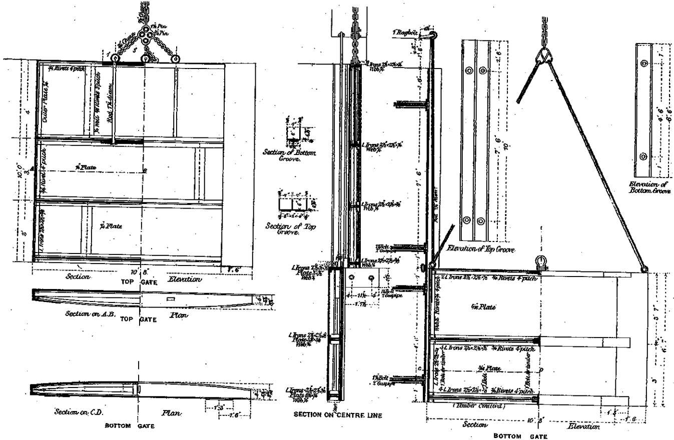


Dimensions in Metres

REGULATING APPARATUS.

DETAILS OF GATES AND GROOVES.

Scale ¼" = 1 Foot.

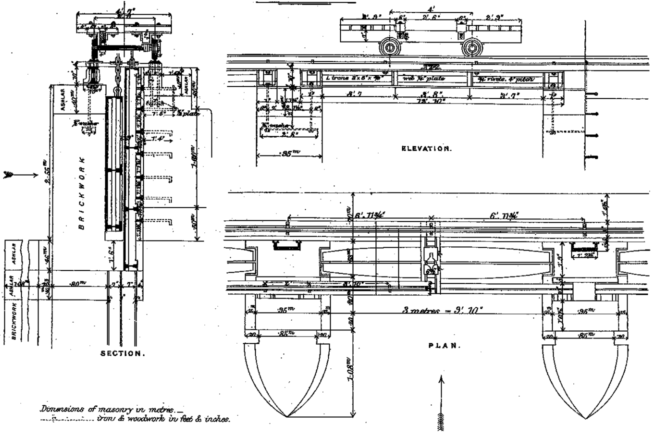


IRONWORK DESIGNED BY COL. WESTERN AND MR A. REID.

REGULATING APPARATUS.

TRAVELLING LIFT GEAR.

Scale ¾" - 1 Foot.



IRONWORK DESIGNED BY COL. WESTERN AND MR A. REID.

design of regulators, I give details of regulators recently constructed and compare them with typical works in France, India and England.

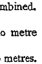
"*Gangara Regulator on the Rayah Tewfiki Canal (Egypt).*—The Gangara regulator, designed and built by Colonel Western and Mr. Reid, is the first ordinary regulator on the Rayah Tewfiki, and consists of a regulator and lock combined. The lock is 50 metres × 8 metres.

The regulator has 6 openings of 3 metres width each, with piers 1·40 metre wide.

The maximum depth of water is 6·30 metres and the maximum head 3·0 metres. It is built on good stiff clay.

The width of the floor is 16 metres and the depth 1·75 metre. The piers are 11 metres long and 6 metres high and support a roadway on their downstream side. On the upstream side they support towers ·80 metre × 1·40 metre and 2·25 metres high, which carry a girder, while the upstream parapet of the bridge is raised to the same level as the girder. The upstream parapet and the towers carry a line of railway on which moves the travelling crab which works the gates. When not needed for regulation, the gates are housed between the towers and the upstream parapet.

The grooves are double and of cast iron.



The regulation of each opening is performed by two wrought-iron gates moving in the grooves. The lower gate is 1·00 metre high and the upper gate 3·00 metres high. The gates are made of wrought iron with the ordinary arrangement of girder and sheeting on one side. The lower gate is lowered and raised by means of suspension rods which rest in the grooves when the gate is down. The upper gate is raised and lowered by means of chains. The traveller is an ordinary winch on a carriage.

This regulator cost 16,867*l.*, and began working in 1889. The amount of ironwork in each opening is—wrought iron 18,000 kilograms and cast iron 9000 kilograms. The gates and overhead platform of each opening cost 825*l.*

The cost per running metre of floor is 42*l.*

The cost of regulating apparatus per running metre or floor is 34*l.*

The regulating apparatus cost 8·25*l.* per square metre of sluice gate."

"*Rayah Tewfiki Canal Head Regulator (Egypt).*—This regulator is at the head of the Rayah Tewfiki Canal where it takes off the main Nile. It was designed and built by Colonel Western and Mr. Reid, and opened in 1889.

The soil is a very light sand full of powerful springs; a worse soil could scarcely be found anywhere for a work of this kind.

The work consists of 6 openings of 5 metres width each, with piers 2 metres wide. On the left hand is a lock 50 metres × 8½ metres.

The maximum depth of water is 9 metres and the maximum head 4 metres in flood, so that this regulator is a good type of a heavily strained work on a bad foundation.

The floor proper is 24 metres in width and 2·5 metres in depth, with an upstream masonry apron 22 metres wide and 1·50 metre deep, and a downstream masonry apron 10 metres wide and 1·5 metre deep. There are 10 metres width of pitching upstream and 20 metres in width downstream of the aprons. The piers and abutments and lock walls are founded on circular wells of 2·5 and 3·5 outside

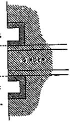
diameter respectively. These wells go down to a depth of 6 metres below the level of the top of the floor.

At a distance of 14 metres upstream of the floor proper, and again at a distance of 7·5 metres downstream of the floor, are rows of rectangular wells 3·5 metres × 2·5 metres in outside measurement which descend to a depth of 6 metres below the level of the top of the floor. The wells are 0·30 metre apart, and the spaces between are piled off and filled with quick-setting concrete, so that these two rows of wells are like two solid curtains. The upstream curtain keeps off springs and the downstream curtain protects the work from scour. The wells were sunk by Bull's patent dredgers after the ordinary Indian method.

The piers are 15·5 metres in length at bottom and 9·5 metres high. They support a roadway 11 metres above floor level. Upstream of the bridge the piers support towers 1·60 × 2·60 and 2 metres high, which carry a girder. The top of the girder and the top of the upstream parapet of the bridge are at one level. They carry a line of railway on which runs a powerful winch for lowering and raising the gates.

Below the main arches are blind arches 1·50 metre wide, so that each sluice is a clear opening 5 metres wide and 7·5 metres high.

The regulation of each opening is performed by two wrought-iron gates moving in separate grooves and raised and lowered by the travelling winch. The two grooves are spaced ·30 metre apart and have let in between them horizontal I girders and blocks of ashlar. The grooves are of cast iron.



In each groove there is a gate 3·50 metres high, provided with rollers whose axles are fixed to the gate. Each gate has three rollers on either side.

On the rise of the flood, as soon as the depth of water in the canal is equal to the requirements, both the gates are lowered together until they both reach the floor and the whole discharge of the canal passes over the tops of the gates. On the Nile still rising and necessitating the further closing of the opening, the downstream gate is raised by the winch and regulation is performed entirely by it; the upstream gate remains on the floor until the final complete opening of the regulator after the flood.

The reason why the two gates are lowered to the bottom together and then one of them is raised, is that sufficient power can always be applied to a gate to raise it against a great pressure of water, but without screws or special rollers the gate could not descend against a head of water when the pressure of water ×[d] by the coefficient of friction exceeded the weight of the gate.

The regulator has been working since 1888 and has given perfect satisfaction, even in the very high flood of 1892.

The regulator cost 60,000*l.* including the lock.

The gates and overhead platform of each opening cost 550*l.*

The cost per running metre of floor is approximately 350*l.*

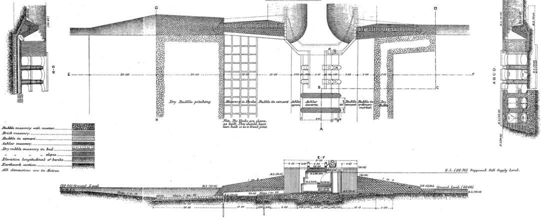
The cost of regulating apparatus per running metre of floor is 110*l.*

The regulating apparatus cost 16*l.* per square metre of sluice opening."

"*Koshesha Escape Regulator* (*Egypt*).—The regulator, designed by Colonel

DESIGN OF THE KOSHESHAH ESCAPE OF 60 OPENINGS OF 3 METRES EACH.

Scale $\frac{1}{400}$



Western and Mr. Reid and constructed by Mr. Hewat, is built on the tail escape of the series of basins from Assiout to Wasta. It consists of 60 openings, each 3 metres wide. The piers are 1·30 metre wide. (Plate XXXI.)

The regulator is founded on good clay soil. The maximum depth of water on the floor was expected to be 6·50 metres, though it rose to 7·00 metres in 1892. The maximum head of water will be 4·00 metres.

The main floor is of masonry 13 metres wide and 2·75 metres deep; the bottom of the foundation is below the minimum summer water level of the Nile. The upstream apron is of masonry 10 metres wide and 1·0 metre deep. The downstream apron is of masonry 12 metres wide and 2 metres deep. Below the downstream apron is 10 metres width of masonry blocks 1 metre deep, and below that again 20 metres in width of rubble pitching.

The piers are 12·5 metres long and 6·5 metres high and support a roadway on their downstream side. On the upstream side they support two towers, each ·80 metre long, 1·30 metre wide and 1·0 metre high.

The depth of each opening is divided into two sluices by an arch thrown between the piers.

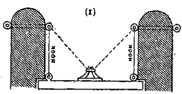
The lower sluice is 2 metres high and the upper 3·5 metres high.

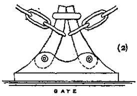
The lower sluice is closed by a vertical gate moving in vertical grooves in the piers.

The upper sluice is closed by a drop gate hinged at its bottom to its floor and falling flat on the floor when open. Both gates are of wrought iron.

The two rows of towers carry girders and a line of railway on which travels the winch which raises and lowers the lower sluice gates in flood when the regulator is being worked. The winch is also employed to raise the upper drop into its vertical position after the flood is over and the regulator is in the dry.*

The upper drop gates are kept in a vertical position (1) by hooks suspended from bolts fixed in the piers and dropping into eye bolts in the gates near the piers, and (2) by chains attached to the same bolts in the piers and clipped by a clip at the middle of the gate. When the gate is up and under water pressure, the hooks take the strain; when the time for opening has come, the hooks are detached and the clip links are struck off and the gates fall instantly.





The regulator has worked through the flood of 1891 and 1892 and has given satisfaction. It cost 62,620*l.*

The amount of iron worked in sixty openings was:—

Cast iron	205,800 kilograms
Wrought iron . . .	367,500 "
	573,300

* There are in reality two winches in order to expedite the opening of the sluices.

The gates and overhead platform of each opening cost 223·5*l.*
The cost of floor per running metre was 90*l.*
The cost of regulating apparatus per running metre was 74·5*l.*
The regulating apparatus cost 14*l.* per square metre of sluice gates."

As the Koshêsha escape is the most important masonry work constructed in the basins in Upper Egypt, I supplement the above information from Major Brown's paper on this work in Vol. XVIII. of the R.E. Professional papers. After describing the work Major Brown quotes from Colonel Western's original Report on the work. Here follow Colonel Western's calculations.

"From a study of the dates of cutting Kosheshah bank in former years we may assume, for purposes of calculation, that the basin escape will be opened on October 22nd, or 19 days before November 10th, the date laid down for the completion of the discharge.

From a comparison of levels it is found that the heads, at the time of opening, will vary from 0·30 to 4·50 metres, and with these heads, less the rise of the river consequent on the discharge, the escape must be designed to pass 100 and 150 million cubic metres per day.

It may be remarked that in order to give an *average* discharge per day of 100 and 150 millions, the first discharge must be increased by one-half, or to 150 and 225 millions; but, considering that the basins have never to date been all full at the same time, and as the cost of the work has been limited to 60,000*l.* or thereabouts, it will be sufficient to calculate for the average discharge for the first outflow, and then arrange, as far as possible, for the maintenance of these same discharges.

Minimum spring level at site of work may be taken as at R.L. 19·00, and foundation line must be below this, or, say, at R.L. 18·50. Floor line may then be placed at 20·50 or above. Assuming this level of 20·50, basin level at 26·70, and river at its minimum 22·20, it will be manifestly injudicious to allow, on first opening, the full depth for discharge of 26·70 − 20·50 = 6·20 metres into a backwater of only 22·20 − 20·50 = 1·70 metre + rise of river, say, 1·00 = 2·70 metres.

The depth of opening must then be divided into two; the first, or upper series, to be opened to discharge the volumes demanded, 100 and 150 millions; and the lower series to be kept as a reserve, and opened only to maintain the discharge as the head decreases, or water surfaces in basin and river fall.

These lower sluices will also be available for filling the Kosheshah basin during the rise of the river, the volume to be passed in being estimated at 400 million cubic metres.

From various trial calculations the upper sluice-gate has been fixed at three metres in depth, or from R.L. 26·70 to R.L. 23·70. Assuming this depth, and the formula for discharge in cubic metres per second, discharge

$$= \tfrac{2}{3} l \times 4{\cdot}43 \sqrt{h}\,(d + \tfrac{2}{3} h),$$

or, for a length of one metre

$$= 2 \cdot 953 \sqrt{h}\,(d + \tfrac{2}{3} h),$$

we shall have discharges as follow, with basin gauge at 26·70:—

River at	Million c.m. per day	Cubic metres per second	Metres of Opening Required for 100 Mn. c.m. Discharge
26·40	0·4054	4·692	246
26·00	0·5920	6·846	169
25·70	0·6814	7·887	147
25·40	0·7480	8·655	..
25·00	0·8089	9·323	..
24·70	0·8419	9·745	..
			Metres of Opening Required for 150 Mn. c.m.
24·40	0·8643	10·004	174
24·00	0·8806	10·192	170
23·70 and below	0·8841	10·233	169

Now the river has only been recorded as above R.L. 26·0 on two occasions during the last thirty years, whilst a large discharge with a low river is most important. It is evident, then, that the 174 running metres of waterway for 150 millions should rule the length.

Assuming a round number of 180, thirty-six bays of five metres, or sixty bays of three metres, are required. (It was decided to build it of sixty bays of three metres.) With the basin at 26·70, we have the following figures:—

River Level before Discharge	First Discharge, million c.m. per day	Raised River Level in Consequence of Discharge	Decreased Discharge, million c.m. per day	Remarks
26·00	106½	26·40	73	Must be supplemented by partially opening lower series.
25·50	131	26·00	112	
25·00	145½	25·70	123	
24·00	158½	24·90	148	
23·00	159	24·10	158	
22·50	159	23·70	159	

The effect on the level at the barrage of opening at the above levels is shown in the following table:—

Basin Gauge	River Gauge at Wastah, five kilometres below Kosheshah		Corresponding to Barrage		Rise at Barrage
	On Opening	After Opening	Before Opening	After Opening	
26·70	26·00	26·40	17·50	17·90	0·40
”	25·50	26·00	17·00	17·50	0·50
”	25·00	25·70	16·50	17·20	0·70
”	24·00	24·90	15·50	16·40	0·90
”	23·00	24·10	14·50	15·60	1·10
”	22·50	23·70	14·00	15·20	1·20

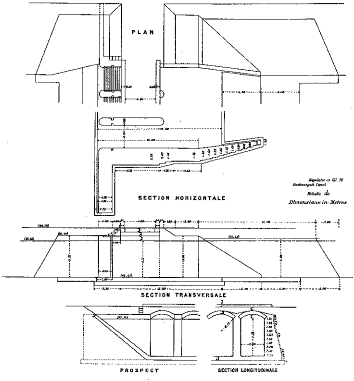
The design for gates has been selected with a view to simplicity, combined with quick opening for the upper tier, and preference has accordingly been given to horizontally pivoted falling gates for upper series, and direct lifted gates in vertical grooves for the lower sluices."

COST OF KOSHÊSHA ESCAPE.

Description of Work	Quantity	Cost
	cubic metres	£
Excavation in foundations	68,708	2,102
Earthwork in approach channels and banks	154,300	4,977
Brick masonry	7,688	7,719
Rubble masonry, ordinary	17,768	14,215
Rubble masonry, in Portland cement	2,108	3,374
Concrete	146	146
Ashlar masonry	1,324	5,694
Dry rubble masonry	16,245	5,265
Unwatering	..	1,152
	lineal metres	
Piling	549	3,323
Ironwork	see below	13,413
Woodwork	..	560
Hutting	..	574
Sundries	..	105
	Total	£62,619

Rates paid for Work.—The rates paid for different descriptions of contract work were the following:—

Earthwork	3¼ piastres a cubic metre.	
Brick masonry	100 ”	”
Rubble masonry, ordinary	80 ”	”
Ditto, in cement	160 ”	”

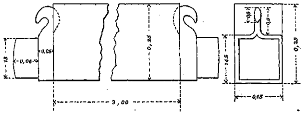

PLAN
SECTION HORIZONTALE
SECTION TRANSVERSALE
PROSPECT
SECTION LONGITUDINALE
Dimensions in Metres

Dry rubble masonry	55 piastres a cubic metre.		
Ditto with Government stone	15	"	"
Ashlar masonry	430	"	"
Piling	600	"	per lineal metre.
Wooden gangways	700	"	per arch.
Timber for winch railway	20	"	per cubic foot.

IRONWORK.

	Quantities	Rates, piastres	Cost £
Wrought iron	367·50 tons	1975	7258
Cast iron	205·80 "	1425	2932
Timber, teak	381·60 cubic feet	100	382
Iron rails	573·30 yards	20	114
Phosphor bronze	6360 lbs.	9	572
Chains	11·057 tons	2050	227
Steel	4·58 "	2470	113
Felt	1172 square feet	.	10
	Total		11608
Winches	2 No.	£668	1336
			12944
Other iron, and cost of erection			469
Total cost, ironwork			£13,413

The regulator at the 26th kilometre of the Rashwania Canal (Plate XXXII.), recently designed and built by Mr. Wilson, is a good example of the type of work employed on the basin canals. The regulation is by means of horizontal sleepers. The sleepers are of the following dimensions and design:—



Scale $\frac{1}{10}$. HORIZONTAL SLEEPER.

Suresnes Weir on the River Seine (France).—This work came into operation in April 1885. It consists of three separate weirs and two locks. The locks are on the left bank. Beginning at the right flank, there is first the weir proper 62 metres in length, then an island, then the escape 62 metres in length, then another island, then the navigable pass 72 metres in length, and finally the locks. The two locks are 160 metres × 12 metres and 60 metres × 8·2 metres respectively.

The three passes are closed by Poirée frames and gates, so that, in high flood, the frames are lowered on the floors which are near the bed level of the river, and the river passes freely without any obstruction of any kind.

The floors are not on the same level, but the downstream floor is always 1·00 metre lower than the upstream floor, and the maximum head of water is 3·30. The depths of water during regulation are as follows:—

The weir	Upstream 4·10	Downstream 1·80
The Escape	" 4·10	" 1·80
The Navigable pass .	" 4·60	" 2·20

The escape is used for ordinary regulation.

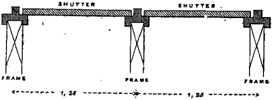
As the navigable pass has the lowest floor, it alone will be considered here.

The floor proper is 15 metres wide and 4·5 metres deep, founded on stiff clay; the upstream apron is 7 metres wide, and consists of 3 metres thickness of clay overlaid by 1·50 metre of masonry. The floor upstream of the frames is raised one metre, and falls gently to the level of the floor on which the frames rest when they are down. This is the arrangement which, after years of trial and experiment, has been found to be the very best to prevent the clogging of the frames with silt when they are lying on the floor.

The downstream apron is 10 metres in length.

The movable parts of the weir consist of Poirée frames and apparatus for regulation.

Frames. There are 57 frames 1·25 metre apart centre to centre. These frames are braced girders of wrought iron, 2·30 metres wide at top, 4·0 metres wide at bottom and 6·0 metres high, supporting a platform carrying rails. The frames are attached at their bottoms to pivots turning in pivot blocks strongly bolted to the floor. These pivots act like hinges, and the frames can be raised by a chain attached to their top either into a vertical position or lowered horizontally on the floor, by means of a powerful crab fixed to one of the abutments. When once the frames are raised and are in a vertical position, they are made tight by tie bars of iron, the rails are connected, and the regulating apparatus is quickly transported from the banks, and the 1·25-metre wide openings between them are closed by means of shutters or curtains, whichever the engineer happens to prefer. At the present time both are being worked side by side to see which gives the best results. The curtains will be described when the Poses weir is being considered Under the Suresnes weir head the Boulé shutters only will be considered, as the engineers of the Suresnes weir prefer the Boulé shutters to the Cameré curtains. The Boulé



shutters are wooden panels 1·25 metre × 1·0 metre, which slide up and down the upstream faces of the frames and close the openings between the frames. The frames are ⊥ in shape on their upstream faces, and so the shutters are kept in position by the force of the water pressing them against the frames, the ⊥-shaped frames

preventing them from moving horizontally. These panels are raised and lowered by means of a travelling crab with a ratchet bar. The Boulé shutters are exceedingly simple and work well.

The frames and shutters and general arrangement look complicated, but they work well and simply, there being a recess in one abutment and an ingenious arrangement for housing the end frames when they lie down.

The frames can be lowered in three hours and raised in five hours. As the pivots of necessity must have some play in the pivot blocks, the frames can never come into one straight line exactly, and the leakage is not inconsiderable. I ought to add here that the leakage is principally owing to the large number of Cameré curtains employed. The Boulé shutters make a far more complete closure than the curtains can. In moving down the frames also, the shutters push all the rubbish sticking to the frames more or less out of the way; while the curtains can do nothing to remove the rubbish, they simply unfold themselves over it and make a poor closure when there is much rubbish. No complete closure of a river could be attempted on this system, and even on the Seine, where they pass a minimum discharge of 45 cubic mètres per second, they need considerable additions in the shape of cover pieces to keep up the water to the desired height. Besides this, the Seine is wonderfully clear of rubbish floating down, but on the Nile or Egyptian canals, where the amount of Indian corn stalk and rubbish which floats down the current is always considerable, the frames would soon be completely buried under rubbish and regulation would be very difficult indeed.

Each frame of the navigable pass cost 60*l.*, and the ties and additions 8*l.* per frame. The frame work therefore cost 56*l.* per running metre.

The movable regulating apparatus, consisting of shutters, travellers, etc., cost 74*l.* per running metre, or $\left(\frac{74}{4 \cdot 6}\right)$, 16*l.* per square metre of submerged area.

The total regulating apparatus of frames and shutters, etc., cost $\frac{56 + 74}{4 \cdot 6}$ *l.*, or 28·2*l.* per square metre of submerged area.

The masonry of the floor cost 400*l.* per running metre.

The total cost of the weir was therefore:—

Masonry floor	£400 per running metre.
Movable frames	56 " "
Regulating apparatus	74 " "
	£530 per running metre.

This sum does not include the charges of river training.

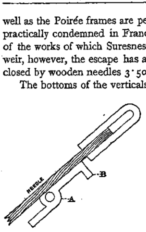
The following information might be useful:—

In the navigable pass there were 7365 cubic metres of masonry, including ashlar; this cost 28,669*l.*, or 3·9*l.* per cubic metre for masonry in place in the foundation.

Pont aux Anglais Weir on the Seine (S. of Paris).—This weir, like that at Suresnes, is provided with Poirée frames, but the regulating apparatus on the weir and the navigable pass is much more complicated. The system of regulation is known as the Chanoine system; a water-tight closure with this system would be an absolute impossibility; while, in addition, a great part of the regulating apparatus as

well as the Poirée frames are permanently below water level. The system has been practically condemned in France itself, as it is no longer a competitor by the side of the works of which Suresnes and Poses are examples. At the Pont aux Anglais weir, however, the escape has a depth of water on the floor of 2·30 metres, and is closed by wooden needles 3·50 × ·08 × ·08 as given in detail on Plate IX.

The bottoms of the verticals rest against a sill on the floor, whilst the upper ends rest against a horizontal bar fixed to the Poirée frames.



The needles are provided with hooks at their upper ends. These hooks are of the shape shown in the figure. They permit of the needles, not only being supported by the horizontal bar at their upper ends, but also of being able to revolve round it when the lower end is freed from the sill.

As a rule, an ordinary lever is applied to the projection B and the needle raised slightly above the sill, the force of the water immediately makes it fly round the bar A and rest on the water. It is removed by hand.

The Poses Weir on the Seine near Rouen (France).—This weir was put into operation in September 1885.

The weir is situated on the the main branch of the river at the downstream end of an island two kilometres in length, while there are three locks and a small weir situated on the smaller branch of the river. The locks are 120 metres × 12 metres × 1·6 metre, 141 metres × 12 metres × 3·2 metres, and 42 metres × 8 × 3·2 metres (the third item is always the depth of water on the sill).

The weir is 244 metres in length, made up of three deep openings of 28·2 metres width each, two escape openings of 28·2 metres width each, and two navigable openings of 32·5 metres and 30·5 metres width respectively. Between the openings are piers of 4 metres width each. The depth of water on the upstream side of sills of the deep and navigable openings is 5·0 metres, and on the downstream side 1·0 metre, or a maximum head of water of 4 metres. The maximum flood level of the river is 6·3 metres above the floor of the navigable passes.

As at Suresnes, the navigable pass alone will be described.

The floor is 13 metres in width and 8·5 metres in depth, resting on compact chalk, with an inconsiderable amount of pitching up and downstream. The floor is at about the bed level of the river.

The piers are 4 metres wide and 23 metres long at base and 21·5 metres long at top; they are 12·5 metres high at the roadway level and 16 metres high at the cutwaters. They are made massive, as they have to stand the horizontal thrust of the water held up at the large openings.

The piers support two iron girder bridges. The lower bridge consists of two main lattice girders 3 metres deep and 3·50 metres apart, supporting a roadway and carrying the iron bar on which the frames are hinged. The upper bridge is 7·50 metres wide and is raised 1·0 metre above the lower bridge. The upstream girder of the lower bridge is the downstream girder of the upper bridge, while the other girder has the same dimensions. The upper bridge carries two lines of rails on which run the travellers which lift the frames out of the river. To this bridge

also are attached hooks for catching and retaining the frames in a horizontal position, so as to leave a clear waterway for navigation when the weir is open.

Each frame, of which there are thirteen in the smaller navigable pass and fourteen in the larger, consists of four iron girders 11·5 metres in length, braced together so as to form a single frame occupying 2·32 metres in length of the horizontal bar to which they are hinged. At about high-flood level the frames support hinged cantilevers carrying a line of railway on which run the travelling crabs for winding and unwinding the curtains by which regulation is performed between the frames. When the frames have to be raised the cantilevers lie flat against the frames, and frames, cantilevers and curtains rise together and are hooked on to the upper bridge. The free passage allowed for navigation between the frames, in their horizontal position, and the high-water level is 4·50 metres. When regulation is necessary, the frames are lowered into position and rest against the sills. They are made truly vertical by driving small wooden wedges between the different frames along the cantilever roadway. The sills are made of iron and are imbedded in the masonry of the floor.

The curtains are 5·50 metres in length and 2·30 metres in width and consist of horizontal pieces of pine wood, ·078 × ·078 in section at the bottom and decreasing gradually to the top, hinged together at their upstream side. A chain passes round the curtain and enables it to be raised and lowered by means of a crab. The leakage through the curtain is inconsiderable after it has been some time in the water, but it is almost impossible to get two curtains to exactly touch each other as they are unrolled against a head of water, and if any rubbish collects against the frames and cannot be removed, the curtains get displaced and allow considerable leakage. I know at Poses they have the very greatest difficulty to maintain the required head when the Seine is running its summer supply, and they have to use cover curtains and other expedients. In Egypt, where the canals are full of rubbish and dura, it would be absolutely impossible to keep the frames clear of rubbish so as to allow the curtain to roll over them. At Poses there are 220 metres in length of opening with a 4-metre head and 45 cubic metres per second as the minimum discharge, while, at the Barrage in Egypt, we have 610 metres in length of opening with a 4-metre head and do not pass ¼ of a cubic metre per second in summer.

The great advantage enjoyed by the Poses system over that at Suresnes is its greater power of being employed for great depths, and the position of the hinges of the frames, which are always above water level instead of below it as at Suresnes.

The masonry floor cost .	£343	per running metre of opening.
The piers cost . . .	170	,, ,, ,,
Total .	513	,, ,, ,,

The girder bridges cost .	£75	per running metre of opening.
The frames . . .	35	,, ,, ,,
The curtains . . .	13	,, ,, ,,*
The machinery . .	5	,, ,, ,,
	£128	or 25·3 per square metre of water surface.

As the masonry cost 513*l.* per running metre, including the pier, the navigable pass cost 641*l.* per running metre.

* Or 2·5*l.* per square metre.

I consider Poses the best weir I saw in France. Though complicated, it works easily and is wonderfully complete in its details.

Belleeck Weir on the Lough Erne outlet (Ireland).—The weir consists of four openings of 8·90 metres width each, with piers 2·40 metres wide. The depth of water is 4·35 metres and the maximum head 4·35 metres. The weir is founded on very solid limestone rock. The piers are 13·8 metres long and 2·40 metres broad for a height of 5 metres above the sills; on these piers are erected masonry towers 2·4 metres wide and 2·7 metres long to support the light lattice bridges which carry the lifting gear and provide a footway and space for working the sluices by hand power.

The regulation is performed by Stoney's patent gates. The main principle of these sluice-gates is the reduction of friction by putting a train of live rollers between the moving surfaces. Each roller frame is kept in position by a chain fastened at one end to the girder bridge over the opening, passing under a pulley fixed to the top of the frame, and then attached at the other end to the top of the gate. The gate in moving confers on the roller frame a velocity equal to half its own rate of motion. At Belleeck, the lifting of the gate is done by two 10-centimetre double-threaded screws of 5 centimetres pitch; there is a screw at either end of the gate, working in a nut fixed to the gate itself. The gearing is so arranged that each gate may be lifted by one man, who takes forty-five minutes to raise a gate 3 metres. The motion is as easy when the gates are holding up the full head of water as when they are in the air. Each gate weighs 13,000 kilograms, and there is no counterweight.

The maximum pressure on a gate is 86 tons, and as I had found by experiment at Ipswich that the pressure needed to start one of these gates was only about $\frac{1}{80}$ of the weight, I was not surprised that the water pressure was really insignificant compared to the weight of the gate.

The staunching at each vertical edge is done by a 5-centimetre turned bar, which hangs freely from the gate in a V groove, one side of which is formed by a planed casting fixed to the pier, and the other by a similar casting on the gate, coming within 1 centimetre of each other at the angle of the V.

Each opening cost 1000*l.* exclusive of the masonry, so that the regulating apparatus cost $\left(\frac{1000}{8\cdot 9 \times 4\cdot 35}\right)$, or 26*l.* per square metre, or 112*l.* per running metre.

The gates were completed in 1884 and have worked perfectly ever since. Each sluice can be made absolutely water-tight when desired.

Lock Regulator Sluices and Weaver Sluices on the Manchester Ship Canal (England). The Weaver sluices consist of some fourteen openings of 9·10 metres width each, with piers of 2·80 metres width. The depth of water is 5·50 metres, and that also is the maximum theoretical head.

The works here are subjected to the action of a very heavy sea. The foundations are of no interest, as good sandstone is met with almost immediately.

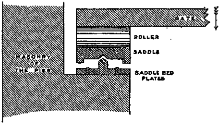
The piers are 11·50 metres long and 6·10 metres high, with towers 5·30 metres ong and 5·10 metres high, to carry the regulating apparatus and to allow of the housing of the gates when the regulator is open.

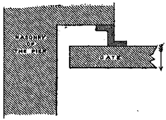
The regulation is performed by Stoney's patent roller gates. The sills are of iron but not brought to a sharp point as ordinarily, for the gates have been designed capable of holding up water on either side.

The towers support light girder bridges, with the girders 1·20 metre deep

and 3·20 metres apart, supporting roadways which carry the pulleys for the counterpoises and the winches for raising and lowering the gates.

The gates are constructed of steel and consist of the ordinary arrangement of girders with sheeting on one side. The gates are perfectly balanced by counter-





poises by means of four wire ropes passing over two pulleys, one at either end of each gate. The winches for putting the gates in motion are at the middles of the bridges and are worked by hand.

The grooves have planed ⊥-shaped girders firmly fixed to their downstream faces as saddle-bed plates. The saddles are of the same width as the length of the rollers and ensure the rollers being always in touch along their whole length, both with the gates and bearing surfaces of the saddles which transmit the pressures to the piers. The roller frames are supported in the same manner as they are supported at Belleeck.

The maximum pressure of water on one gate will be $\left(10 \times 5\cdot5 \times \frac{5\cdot5}{2}\right) = 150$ tons, and as the coefficient of friction is $\frac{1}{80}$, the force needed to move the gate against the pressure of the water will be 2 tons or 2000 kilograms.

The gates are made water-tight by double L irons fixed to the upstream ends of the grooves and resting against the gates.

The Lock Regulator or Byewash Sluices.—These regulators have each three openings of 9·10 metres width each, with piers 3 metres wide. The foundations are on good sandstone.

The maximum depth of water and the maximum head possible is 7·90 metres.

The piers are 13·2 metres long and 9 metres high, with towers 5·5 metres long and 6 metres high for the regulating apparatus and allowing of the housing of the gates when the regulator is open.

The other details of this regulator are similar to those of the Weaver sluices, except that the bridges are 3 metres wide and 10·5 metres above flood level.

The sills are of wrought iron and are brought to a sharp point projecting well above the floor to ensure their being always clear of rubbish.

The maximum pressure which will ever come on any one of these gates will be $\left(10 \times 7\cdot9 \times \frac{7\cdot9}{2}\right) = 300$ tons approximately. The resistance to be overcome in raising the gates will be $\left(\frac{300}{80}\right)$ = about 4 tons or 4000 kilograms.

Dowlaishweràn Regulator (Madras, India).—The regulator was built in 1846–1848 and has been working since.

There are three main openings, each 12·19 metres wide, with piers 2·19 metres wide. Each main opening is subdivided into five openings of 1·83 metre width by piers ·76 metre wide. There is a small lock on the left flank.

The maximum depth of water on the upstream side is 6·20 metres, and the maximun head is 3·80 metres.

This work is constructed entirely on coarse sand.

The main floor consists of a mass of masonry 10 metres, wide and 1·8 metre deep, with a downstream apron of masonry 5 metres wide and 1 metre deep. The downstream curtain is a row of wells 1·30 metre in external diameter, which descend to a depth of 3 metres below floor level.

The floor seems exceedingly light for such an important work built entirely on sand.

There are 10 metres of pitching upstream of the floor and 40 metres of pitching downstream of the floor, with a thickness of from ·80 to 1·30 metre.

The main piers are 10·3 metres long, 2·19 metres wide and 3·5 metres high; they support arches of 12·19 metres span.

The cutwaters are 6·70 metres high.

The smaller piers are ·76 metres wide, 3·4 metres long and 3·05 metres high, supporting arches and a blind wall 1 metre wide between the lower arches and the main arch.

At a height of 2·44 metres above the floor, the small openings are spanned by ashlar lintels ·25 metres wide, which support a blind wall between the lintels and the lower arches.

The area of each sluice opening is therefore 1·83 × 2·44 metres.

The cutwaters of the smaller piers are also 6·70 metres high.

The cutwaters are provided with double grooves in which move two wooden gates, each 1·30 metre in height, which regulate the openings by means of screws. The capstans for working the screw lifting gear are at the level of the tops of the cutwaters.

Bobberlanka Regulator (Madras, India).—Built in 1879 at a cost of 8081*l.*

There are five main openings of 7·32 metres width each, with piers 1·22 metre wide.

Each main opening is subdivided into 3 openings of 1·83 metre width each by piers ·92 metre wide.

The maximum depth of water on the upstream side is 6·20 metres, and the maximun head 3·80 metres.

The regulator is built entirely on coarse sand.

The main floor consists of a mass of masonry 14 metres wide and 1·80 metre thick, with a downstream apron 8 metre wide and 1 metre thick. The downstream curtain is a row of wells 1·80 metre external width and 6·0 metres below the level of the floor. The upstream curtain is a double row of wells 1·80 metre external width and 6 metres below the level of the floor. The space between the two rows of wells of the upstream curtain is filled with concrete. The total width of the upstream curtain is 5·3 metres.

The pitching downstream is 15 metres wide and 1 metre deep. The upstream pitching is 6 metres wide and 1 metre deep.

The main piers are 8·25 metres long, 1·22 metre broad, and 3·05 metres high, and support an arch 7·32 metres span. The cutwaters are 7 metres high.

The smaller piers are 4·0 metres long, ·92 metre wide and 2·6 metres high, supporting arches and a blind wall 1 metre wide between the upper and lower arches.

The sluice openings are 1·83 metre × 3·05 metres.

The cutwaters of the smaller piers are 7·00 metres high.

The cutwaters are provided with treble grooves in which move 3 gates; each gate is 1·05 metre high and made of wood. The gates regulate the sluices by means of screw lift gear. The capstans for working the gear are at the level of the tops of the cutwaters.

Narora Weir Undersluices (India).—The Narora weir is a solid dam thrown across the Ganges River, with its crests 3 metres above the normal bed level of the river. (See Plate XXI.)

The undersluices are situated near the canal head in order to keep the deep channel of the river near the canal head. The floor is on the same level as the canal bed. The undersluices consist of openings of 2·13 metres width each, with piers ·76 metre wide between.

The maximum depth of water is 4 metres and the maximum head 2·5 metres.

The works are founded on sand.

The main floor is 15·3 metres wide and 1·80 metre deep, with an upstream curtain of wells 5 metres below floor level and 1·83 metre broad. There is also a downstream curtain of wells 3·5 metres below floor level and 1·83 metre broad. Downstream of the floor is an apron of pitching 30 metres long and ·50 metre deep. The upstream apron is 9·5 metres long and 1·3 metre deep.

The undersluice regulating gates are over the upstream wells.

The piers are 8·70 metres long and 4·5 metres high. They support a roadway 5·70 metres above the floor. Upstream of the roadway the cutwaters are raised to the same level as the roadway.

The sluices are 2·13 metres wide and 3·3 metres high and are regulated by wooden gates 2·4 × 3·3 metres moving in vertical grooves, and raised and lowered by means of a winch travelling on rails about 7 metres above the floor level.

The floor cost about 120*l.* per running metre. The work was completed in 1874 and has been working since."

Silt Deposits in Canals.—The reduction of silt deposits in canals is a work which has occupied the attention of canal engineers in every age. In a discussion on an irrigation paper at the Institute of Civil Engineers, General Rundall, C.S.I., called to mind the remark once made by an old irrigation engineer in India that he believed when he died the letters SILT would be found engraven on his heart. The silt deposit which is caused by excessive velocities eating down the banks and filling up the beds has been successfully combated in both Upper and Lower Egypt, and the methods adopted have been given in great detail in Chapters V. and VI. The silt deposits which come from the checking of the velocity of water are far more serious, and it is to them only that reference is now made. To find out the velocities at which silt deposit takes place in canals taking off suitable points of the river I instituted a series of very careful experi-

ments in four canals in Lower Egypt during 1884, 1885 and 1886, and came to the following general conclusions. In canals with their heads suitably placed:—

1. A mean of velocity from ·70 to 1·00 metre per second does not cause any appreciable deposit.

2. A mean velocity of ·60 metre per second causes a deposit of ½ a metre in an ordinary flood.

3. A mean velocity of ·50 metre per second causes a deposit of 1 metre in an ordinary flood.

4. A mean velocity of ·40 metre per second or less than ·40 per second causes mud deposits.

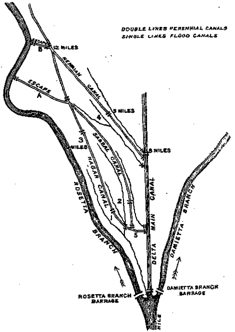
August and September are the chief months for silt deposition, while in October the water in the river is much less heavily charged with silt. In November and December the water is comparatively clear, and if advantage is taken of this clear water it can be utilised (and has been so utilised) to scour out the deposits of fine mud in the canals before the mud has had time to harden and consolidate. By opening all the regulators and inducing a strong current, considerable quantities of light silt can be removed from the beds, and especially the sides of the canals.

If to every ordinary canal which had its head suitably placed there could be ensured, a velocity of from ·70 metre to 1 metre per second in flood time there would be practically no silt deposit. Before this velocity could be obtained a regular flow of water from head to tail would have to be ensured. During the six years that I held charge of the Second Circle, there was no subject to which I devoted more attention than to this one of silt deposits, and I found that if a definite method were adopted and rigidly adhered to, the results were really extraordinary, while the least inattention or carelessness was attended with heavy penalties. Nor was this at all extraordinary considering the rate at which silt can deposit if conditions are favourable. During the flood of 1885 I noticed that the left half of the Damietta Barrage was silting fast, and had daily measurements made in the second opening from the left flank. The following facts were disclosed:—

The depth of silt	deposited on the	14th	August was	·50	metre.
"	"	15th	"	·12	"
"	"	16th	"	1·30	"
"	"	17th	"	1·10	"
"	"	18th	"	·08	"
"	"	19th	"	·50	"
"	"	in 6 days	.	. 3·60	metres.

and altogether, between the 9th and 26th of the month, or in 18 days, 6·40 metres of silt were depositied until the silt came to the water's edge.

The accompanying sketch gives the Naggar, Sabbal and Nenaiah canals, which used to silt up in cases to the water surface of the canals in flood, and out of which the corvée cleared in 1884 as much as 900,000 cubic metres, to accomplish which some 18,000 men worked for 60 days. These heavy deposits were due to very simple causes. To ensure flush irrigation in the upper reaches of the canals the regulators 1, 2, 3 and 4 on the perennial canals in the sketch were partially closed in flood and the velocities checked. There were, moreover, no escapes for these three large canals which eventually tailed into a single canal. By constructing regulator No. 5 at the head of the Sabbal Canal, closing it hermetically in flood and digging the new flood canals which are shown in single lines, I was enabled to give high-level water in flood to the high lands, independently of the deep perennial canals. For these canals I provided two new escapes *A* and *B*, demolished regulator (1), and completely opened the regulators 2, 3 and 4 in flood. The result was that there was movement everywhere, and in 1887 the total quantity of silt deposited was only 30,000 cubic metres.



Among other methods employed by me with success for reducing silt deposits were; the partial closure of the heads, and complete opening of the

second regulators of the very deep canals every alternate week in flood, so that a current was generated and deposits were prevented; the building of masonry regulating heads on all groups of minor canals, so that in summer water was held up to command the highest canal and the highest canal was not silt-cleared as before to the level of the lowest; during summer, regulators were fully used, but they were kept fully open in flood when possible; and, lastly, the area irrigated on each canal was found and the supply proportioned to it, so that the favourably situated canals no longer took more than their share, and more was consequently available for the unfavourably situated canals without increasing the discharges at the heads of the main canals. Besides the great saving of labour and money in silt clearances, there were three other distinct advantages: 1st, the rich Nile mud, instead of being deposited into the canals was carried on to the fields; 2nd, all the canals had beds sufficiently low to take in water for irrigation during the winter, before the annual clearances which generally took place between February and April; 3rd, these same canals were open to navigation carried on through the central arches of the regulators, many of which were provided with drawbridges.

We have so far considered the question of dealing with the water after it has entered the canals, and all the statements and observations have had reference to canals "with their heads suitably placed." We now come to the management and control of the water before it has entered the canals, so that the canal heads may find themselves suitably placed. The Nile in flood, like all silt-laden rivers, has worked out for itself a mean width and depth and slope which enables it to carry on the normal quantity of deposit which it has brought with it from its different tributaries, but this quantity is not constant in quantity or quality. In certain reaches owing to sand banks and shoals it finds itself at a certain stage of the flood occupying more than its normal section, and immediately it loses some of the heavier matters carried in suspension, and it is then less heavily charged with silt than it normally is, but it is at the same time in this stage particularly capable of eating away sandy foreshores and becoming heavily charged with coarse silt. Now if a canal takes off from a reach of the river where the river is in excellent train and is carrying its normal quantity of silt, we say that a canal head in such a reach is suitably placed. If, again, a canal head is placed in the middle of a severe curve on a dense clay reach downstream of big shoals and sand banks where the river has left much heavy deposit and finds itself comparatively free of silt, we say that the canal head is excellently placed provided the curve is permanent. But if a canal head is placed just dowstream of a sandy foreshore which the river has been attacking and from which it has been charging itself with much coarse deposit, we say the canal head is most unsuitably placed. It is on these accounts most important that canal heads should either be placed at natu-

rally suitable places, or if the canal heads are already placed the reaches of the river should be made suitable. All the natural canals fed by the river take off from heavy curves in stiff clay where the river is not charged with silt in an inordinate degree. Such canals are particularly free from silt deposits if carefully handled. Artificial canals, on the contrary, which have had their heads fixed without proper forethought, are singularly liable to silt deposits. The river upstream of their heads is perpetually changing its course, and one year passing the canal head lightly charged with silt and another year laden with silt. In the years that the river is lightly laden the silt deposits in the canals are insignificant provided the canal has not been mismanaged. In the years that the river is laden with silt, the silt deposits in the canals are heavy whether they are well or ill managed. The Sohagia and Kasra canals in Upper Egypt are excellent examples of well placed natural canals. Linant Pasha in his memoirs, speaking of the Bajuria Canal in Lower Egypt which had a very well placed head in pre-Barrage days, states that it never silted. The Khadrawia never silted if it was carefully managed. The Ramadi, Fadilia and Girgawia canals in Upper Egypt, on the contrary, are examples of artificial canals badly placed which are ordinarily inundated with silt. Such canals should have the river for a good 10 kilometres upstream of them, well trained and fixed on the principles just enunciated, and the silt deposits would immediately decrease. The Ibrahimia Canal in Upper Egypt is an example of a canal with its head badly placed. This canal has been most judiciously treated during the last fourteen years but is still at the mercy of the river. For years the river kept eating away the banks just upstream of it and deluging the canal with silt. During the last two or three years a shoal has formed upstream of the canal head, the river has parted with its silt to form the shoal and passed the canal head comparatively free of silt, and the silt deposits have been quite insignificant. The Rayah Menoufia at the Barrage was perfectly free of silt for years while the river passed its head comparatively free of silt. Ever since operations were undertaken to eat away the western half of the island upstream of the Barrage the canal has been deluged with silt. This rectification of the river bank was necessary in the interests of the Barrage, but the heavy silt deposits at the Rayah Menoufia have represented the price which has had to be paid. This rectification will soon come to an end, and if then the Rayah head is suitably placed near the Rosetta Barrage as explained in Chapter IX., the silt deposits will cease.

There is yet a third class of silting up of canals, of which much has been written in Chapter VIII. This silting up takes place in the lower and tail reaches of canals, when the discharge and velocity in flood are temporarily or permanently reduced, and the channel section accommodates itself to the new conditions. It is on this account that weekly reductions of supply or rotations in flood are to be deprecated unless all the regulators

from head to tail are fully opened at the same time. With all the regulators fully open, scour can be obtained, and very recent silt deposits can be most successfully swept out of canals. But this can only be done on canals with proper escapes. On canals without escapes the lower regulators have to be shut (unless the canal head is hermetically shut), and then begins the silting up of the lower reaches so deprecated in Chapter VIII. This same silting up takes place if the discharges are permanently reduced. Suppose a canal discharging 100 cubic metres per second in flood at its tail has a regulator built on its tail reach in order to raise the water level, and has constructed from the upstream side of the regulator two minor canals or "genabias," capable of discharging between them 30 cubic metres per second. The tail reach of the canal will silt up to suit a discharge of 70 cubic metres per second, and unless the minor canals are made capable of discharging 30 cubic metres per second from head to tail and continued to the lake, the canal will have lost escape power represented by 30 cubic metres per second. It is this perpetual dwindling down of canals which is a serious feature of perennial irrigation as actually practised.

Navigation in Egypt has no friends in authority except the Irrigation Department. It is ordinarily much discouraged by the Government, in order to compel traffic to move along the railways, which are practically a Government monopoly. This is very detrimental to the interests of the country, since nearly all the cotton is grown along the deep navigable canals, while of necessity all the pumping stations requiring coal are on the canals. By means of heavy tolls at locks and other obstructions, the traffic is moved out of its natural channels. The Kasr el Nîl bridge is opened for boats once per twenty-four hours. The bridge obstructs navigation and is a convenience to the owners of carriages and foot-passengers. The latter, however, pay no tolls, but the boats which are delayed and harassed at the bridge have to pay heavy tolls. When the railway extension was made from Shebinel Kom to Menouf it was found that the merchants preferred the navigable line of the Bajuria Canal. To force traffic on to the railway heavy tolls were put at the Dalgamûn railway bridge and navigation was defeated. This war against navigation is specially hard on Egypt, as boat building is the principal industry of the country and navigation employs more hands than anything except agriculture. And as, moreover, the country is flat, and the current generally in one direction and the wind in the other, one would imagine that the Government would befriend navigation instead of considering it a dangerous rival to be suppressed in every possible way. For it must be remembered that not only are heavy tolls put on the boats, but the drawbridges are opened as seldom as possible, and no tugs or apparatus provided to help boats through at the times of opening in case of the wind dropping or an accident of any kind happening. A boat may be

delayed for twenty hours with a favourable wind blowing all the time, and if the wind drops just when the bridge is opened it may have to wait another twenty-four hours.

The following table gives dimensions of typical boats and steamers on the Nile:—

DIMENSIONS OF NILE BOATS AND STEAMERS.

Description of Boat	Ardebage	Extreme Dimensions		Draught		Height of Mast	Remarks
		Length	Breadth	Empty	Full		
		metres	metres	metres	metres	metres	
Cargo	1300	26·00	7·60	1·00	2·20	..	7 ardebs = 1 ton.
"	1050	26·00	7·00	·80	1·90	15·90	To find tonnage divide ardebage by 7.
"	1000	24·00	6·60	1·00	2·00		
"	907	23·60	6·61	·80	1·90		
"	777	21·10	5·90	·80	1·90	16·15	
"	724	21·46	5·70	·80	1·60	11·10	
"	681	20·80	5·75	·80	1·60	14·20	
"	658	21·00	6·14	·70	1·40	13·00	
"	600	20·72	5·90	·70	1·40		
"	556	19·80	5·60	·90	1·60		
"	550	19·70	5·60	·70	1·60	12·80	
"	500	19·40	5·34	·60	1·40		
"	475	19·80	5·32	·80	1·40		
"	455	18·67	5·26	·80	1·40		
"	438	18·60	5·50	·80	1·50	11·60	
"	406	19·30	5·20	·70	1·60		
"	385	18·06	5·00	·70	1·40		
"	369	17·51	5·03	·70	1·20	11·70	
"	333	16·20	4·64	·70	1·50		
"	320	16·70	4·70	·70	1·40		
"	284	15·47	4·65	·60	1·20	10·50	
"	228	14·72	4·34	·70	1·20	10·10	
"	202	14·10	3·84	·60	1·10	6·50	
"	188	13·35	3·74	·70	1·00	8·20	
"	171	12·34	3·74	·70	1·00		
"	130	13·67	3·71	·60	1·10		
"	120	12·10	3·55	·60	1·00		
"	98	11·20	3·40	·60	1·00	6·50	
"	69	10·56	2·75	·40	·80	5·90	
"	55	8·70	2·72	·40	·70	5·70	
"	32	7·60	2·30	·35	·70		
"	23	7·30	2·20	·30	·60	5·00	
"	15	6·32	1·86	·30	·50		
Dahabias	?	35·40	5·70	·70	1·00	14·20	House-boats
"	?	33·50	5·80	·60	·80	14·50	
"	1280	30·60	5·80	·70	·80	14·50	
"	1241	29·40	5·64	·70	·80	14·00	
"	1106	29·40	5·64	·90	1·00	14·00	

DIMENSIONS OF NILE BOATS AND STEAMERS.—*continued.*

Description of Boat	Ardebage	Extreme Dimensions		Draught		Height of Mast	Remarks
		Length	Breadth	Empty	Full		
Dahabias		metres	metres	metres	metres	metres	
"	587	22·90	4·50	·60	·70	10·00	Registered 350 ardebs.
"	?	30·00	4·70	·70	1·00	13·50	
"	250	16·90	3·20	·50	·60	7·20	
"	263	17·00	3·04	·50	·60	8·00	
Steamers	Nazaratia	53·00	9·30	1·25	1·30		
"	Faiz Rabbani	62·75	11·20	..	1·20		
"	Fa z Zafier	72·0	11·60	..	1·6		
"	Fairouz	61·70	12·20	..	1·2		
"	Hehia	60·70	11·70	..	1·4		
"	Rameses	72·3	15·6	..	·95		
"	Mohamed Aly	53·4	10·4	..	1·20		
"	Tewfik	50·60	11·0	..	·95		
"	Amenartas	42·70	12·8	..	1·25		
"	Memphis	51·9	13·1	..	·80		
"	Philae Elephantine	25·6	7·7 Including paddle boxes.	..	·80		

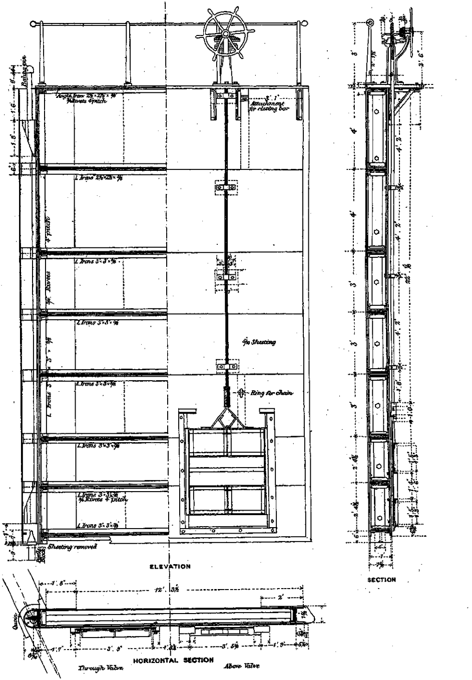
Complete information about navigation difficulties and tolls will be found in 'Commission d'étude des droits de Navigation,—Rapport—Cairo, 1888,' published by the Egyptian Government. Colonel Western was one of the Commission, and thoroughly examined the whole question.

Plate XXXII. gives details of the lock gates at the Melig regulator, and the opening and shutting apparatus. It will be noted that the hollow grooves and sills which are fixtures are of cast iron. The gates themselves are constructed of wrought iron. The valve openings are large compared to the area of the gate, to allow of a considerable discharge during flood, and thus prevent silt deposits in the locks. The preceding table gives details of a number of cargo boats, steamers, &c., in Egypt.

On the main lines of canal the locks should at least be large enough to pass boats of 1000 "ardebs," and therefore have the following dimensions: 30 metres × 8 metres × 2 metres. It has been decided to have locks of 50 metres × 8 metres × 2 metres on the main lines in Lower Egypt. On the Ibrahimia and Ismailia canals the locks are 35 metres × 8½ metres × 2 metres. For minor canals where 250-ardeb boats only ply, the locks

MELÍG LOCK GATE.

Scale ¾ = 1 Foot.

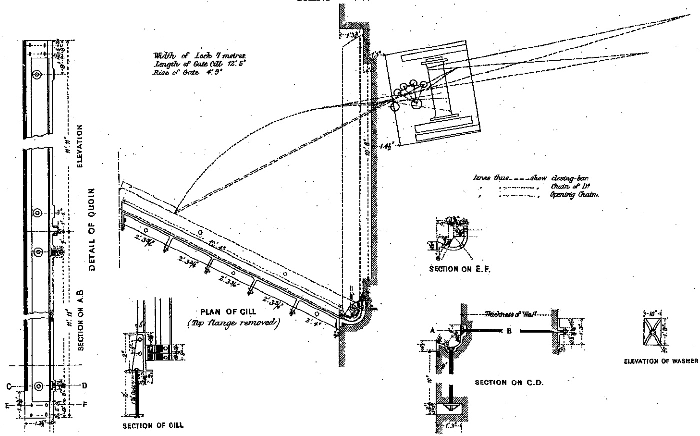


Ironwork designed by Col. Western and Mr A. Reid.

MELÍG LOCK.

DETAILS OF QUOINS AND CILL.

Scale ¼" = 1 Foot.

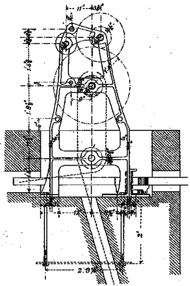


IRONWORK DESIGNED BY COL. WESTERN AND MR A. REID.

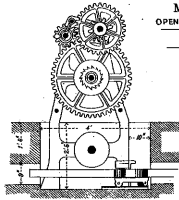
MELIG LOCK.

OPENING & CLOSING GEAR.

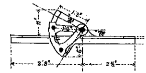
Scale ⅓" = 1 Foot.



ELEVATION



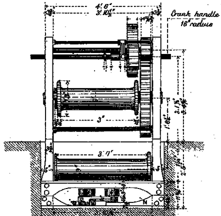
SECTION ON A.B.



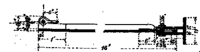
PLAN OF ROLLER PLATE & CASTING M.



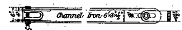
PLAN OF ROLLER PLATE INVERTED



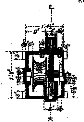
FRONT ELEVATION



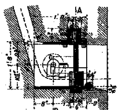
LONGITUDINAL SECTION OF CLOSING BAR.



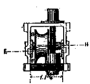
PLAN OF CLOSING BAR



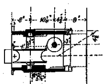
SECTION ON A.B.C.D.



SECTION ON J.K.



ELEVATION



PLAN ON E.F.G.H.

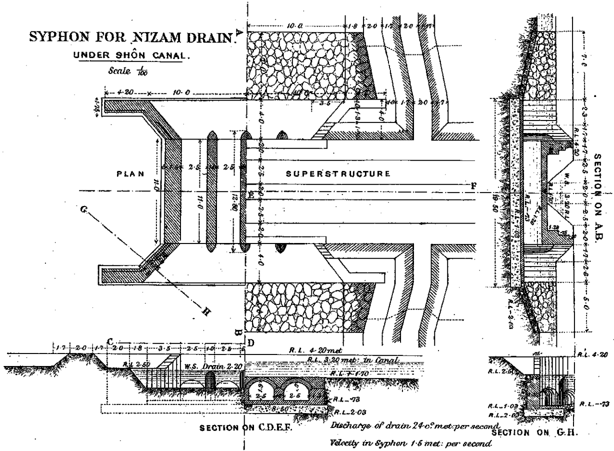
DETAILS OF ROLLER BOX.

DESIGNED BY MR A. REID

SYPHON FOR NIZAM DRAIN.

UNDER SHÔN CANAL.

Scale 1/100

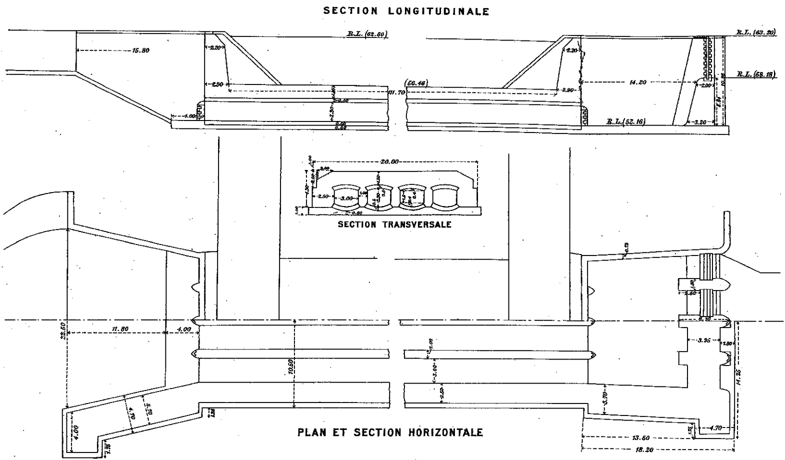


Discharge of drain 24 c.m. met: per second.

Velocity in Syphon 1·5 met: per second.

SIPHON UNDER SOHAGIYAH CANAL

SYSTEM NORTH SUHÂG # 3



Echelle $\frac{1}{200}$
Dimensions in Metres

should be 20 metres × 6 metres × 1·25 metre (a width of 6 metres is necessary to pass boats laden with three bags of cotton laid crossways). In the Berriya, where no cotton is carried, but only rice, dates, melons and fish have to be transported, locks of 20 metres × 4 metres × 1·25 metre will suffice for the traffic. On the Nile itself locks of 50 metres × 12 metres width are necessary for the ordinary steamers. Locks of 15 metres in width alone can pass the double boats of wheat-straw tied together, while widths of 16 metres are needed for the largest new passenger steamers.



Aqueducts, syphons and cross-drainage works are to-day common in the country. In Upper Egypt, on the syphon canals along the strip of high land bordering the Nile, syphons of the very boldest designs were constructed to carry high-level water from an upper basin series under the next basin canal. These syphons were built of coarse masonry, and of slight section, it having been always assumed that both canals would be full of water at the same time. Since these works act only in flood, this assumption was justified when scarcely any canals had regulating heads, but to-day all that is altered. Plate XXXVI. gives a plan of a syphon, constructed by Mr. Garstin in 1888. Plate XXXVII. gives a plan of the Sohagia Syphon built by Colonel Ross on the Girgawia basin canal. Since 1885, wrought-iron pipes, however, have nearly always been used both for aqueducts and syphons. They are generally constructed of ¼-inch sheet iron, butt jointed, and stiffened with L irons at every alternate joint if over 12 feet circumference ; and lap jointed if under 12 feet. Since the sheets in the market are 8 feet × 4 feet, or 6 feet × 3 feet, the pipes are always constructed with their circumference some multiple of the length or width, so that there might be no cutting of plates. The pipes are sometimes laid on a bed of concrete, varying from 1 metre to 25 centimetres in thickness according to the quality of the soil, or they are laid on the hard clay soil and well packed round with clay balls. Where the pipes are used as aqueducts, they are generally supported on wooden trestles.

The table on page 344 gives roughly the weight of these pipes per length of 10 metres, and also the velocity in metres per second and discharge in cubic metres per second, corresponding to different heads of water.

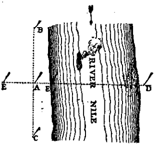
The great advantage of using wrought-iron pipes is that they can easily be transported ; they do not need expensive supervision during construction, and can be put together so rapidly, that the cost and trouble of a diversion for the canal during time of construction is avoided. These pipes can be closed at their ends and floated to their destination. By dredging the foundation where they have to be laid, they can be floated over the site and then sunk without shutting the canal head.

All *discharges* of rivers and canals are generally calculated from Bazin's coefficients. Plate XXXVIII. gives cross sections and velocity observations of the Rosetta and Damietta branches in flood taken by Colonel Western.

¼-INCH WROUGHT-IRON PIPES FOR SYPHONS.

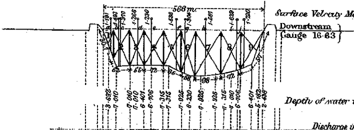
Diameter in Metres	Circumference in Feet	Weight in Tons per 10 Metres Length	Velocity in Metres per Sec.; and Discharge in Cubic Metres per Sec.									
			Head ·10 Metre		Head ·50 Metre		Head 1·0 Metre		Head 1·5 Metre		Head 2·0 Metre	
			V.	D.	V.	D.	V.	D.	V.	D.	V.	D.
·19	2	·32	1·0	·03	2·3	·07	3·3	·093	4·0	·113	4·7	·133
·38	4	·68	1·0	·13	2·3	·31	3·3	·44	4·0	·54	4·7	·63
·78	8	1·40	1·0	·48	2·3	1·10	3·3	1·58	4·0	1·91	4·7	2·245
1·16	12	2·20	1·0	1·06	2·3	2·43	3·3	3·49	4·0	4·23	4·7	4·97
1·55	16	3·10	1·0	1·89	2·3	4·34	3·3	6·23	4·0	7·55	4·7	8·87

A site was chosen where the river was fairly straight on a length of fully 2 kilometres; the most uniform cross section of the river was found by taking a large number of rough cross sections. A peg was fixed in the bank opposite this section. In the accompanying plan, A is this fixed point. Through A, a line B A C was marked, exactly parallel to the direction of the river, making A B and A C each equal to about the observed width of the river. A theodolite or plane table was put up at A, and the point D across the river on the line A D at right angles to B C was fixed. Since A B and A C were both capable of being measured, they were measured, and with the aid of the theodolite or plane table the length A D was obtained. In the line A D or its continuation, flags were put up at E and E′ to direct the man in the steamer on the Nile. The theodolite or plane table was now put up at B or D, and observations made on a steamer or boat on the Nile, which as it got on the line A D threw out a signal and took a sounding either with a line or sounding-rod. The boat or steamer traversed the whole section, and if any gaps were left without soundings, the plane table showed where they were, and they could be immediately filled in. While all this was going on, the nearest river gauge was being observed, and also a temporary gauge erected at the site of the discharge site. The two were afterwards connected by levelling. This



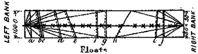
DISCHARGE ROSETTA BRANCH BELOW BARRAGE.

Total Area – 3946 sq.r metres



Section	Sq.r metres	R.	C.	Discharge in C.metres per 24 hours
1.	145·074	4·721	·79	11,793,106
2.	417·246	6·725	·80	41,299,000
3.	362·706	6·595	·80	31,738,300
4.	494·863	6·873	·80	43,303,180
5.	483·715	7·411	·80	51,423,590
6.	453·255	7·815	·80	40,853,470
7.	790·795	8·070	·80	86,766,400
8.	501·080	8·069	·80	56,419,840
9.	297·174	6·220	·80	25,059,240

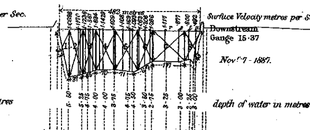
Total 388,658,126 c.metres per day.



Long.l Scale $\frac{1}{10\,000}$
Vert.l Scale $\frac{1}{600}$

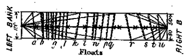
DISCHARGE DAMIETTA BRANCH BELOW BARRAGE.

Total Area. – 1824·8 metres sq.r



Section	Sq.r metres	Mean Velocity
1	86·25	1·0695
2	197·95	1·1175
3	262·75	1·1401
4	274·15	1·1664
5	308·40	1·1172
6	248·20	1·2658
7	352·40	·9241
8	128·20	·4926

Discharge 134,343,602 c.metres per day

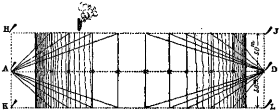


completed the observations necessary for the cross section, which was now plotted, e.g.



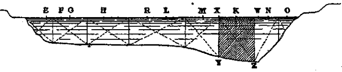
The surface velocity observations were now made.

Two lines, H J and K L were fixed, the former 50 metres upstream of A D, and the latter 50 metres downstream. Between these lines the surface floats were observed. A theodolite or plane table was fixed at A, and the boat or steamer was sent upstream with the floats. An observer stood at H, and another at A. The boat dropped a float into the stream at a distance of about 50 metres upstream of the line H J at a convenient point, and the theodolite or plane table at A followed it until the man at H called out on its crossing the line H J. It was then observed and recorded; this was repeated as the float crossed the line K L. The observers at H and K noted the time. When a sufficient number of well-



placed velocities over the half of the river near A were observed, observations were made for the other half from D. The field work was now over.

On the cross section, the points E, F, G, and C, where the velocities were

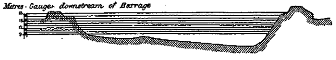


observed, were plotted. The cross section was divided into a number of suitable sections, each ruled by one or more observed velocities. Each section was calculated separately, e.g. the section X Y Z W. Its area was X Y Z W, its wetted perimeter was Y Z; its hydraulic mean depth was $\frac{XYZW}{YZ}$; and the rest followed from Bazin's coefficients and tables.

Referring to the lower figure on Plate XXXVIII., the firm line is the line on which the section was taken, and the crosses the points where soundings were taken. The dotted lines give the paths followed by the floats. Referring to the upper figure, which is a section along the middle line, the numbers 1, 2, 3, 4, 5, &c., show the subsections; while the firm vertical lines show the boundaries of these subsections; and the fine vertical lines the points where the floats crossed the line of section. The observed surface velocity in metres per second is written opposite each float, while below the section are written the areas in square metres, the hydraulic mean depths, the constants for multiplying the surface velocities to reduce them to mean velocities, and the discharges of the subsections in cubic metres per twenty-four hours. The addition of these latter makes up the total discharge of the river. Above the section is written the total surface width in metres, and the total area in square metres; the Barrage down-stream gauge of the day is written on the right hand.

In addition to the discharges obtained from surface velocity observations, others were calculated from surface slope observations. A very careful cross section of the river was taken, as before, on a straight reach of some 3 or 4 kilometres, and at a point where the cross section was fairly uniform, showing that the river here was flowing normally. A section in winter was found more exact than in flood. There was enough water for the river to preserve its normal slope of water surface, and not enough to render the taking of soundings difficult.

Its water surface was compared with the nearest fixed gauge of the river. The section was very carefully plotted, and the water surface was drawn on it, with the corresponding gauge-reading written against it. Horizontal lines 1 metre or ½ metre apart were then plotted on the section, corresponding to the different gauge-readings. The cross sections and



hydraulic mean depths were now calculated for each gauge-reading, e.g. 11, 11·50, 12·0, 12·50, 13·0, &c. For the slope of the river, a long reach of 50 kilometres was taken, as the chances of error were much less than they would have been if 3 or 4 kilometres had been taken. This was very easily done on the Nile, as there were carefully levelled gauges about 50 kilometres apart, in Lower Egypt. The mean slope on this reach of 50 kilometres was taken as the slope for calculating the discharges. Of course on curves the slope varied; but since the cross section had been taken in a carefully chosen normal site, the mean slope would refer to it.

From the calculated velocities and discharges a discharge and velocity diagram was made. This diagram was checked frequently by surface velocity observations taken as shown on pages 344 and 345.

The discharge diagrams for the river, made by me for the Reservoir studies, were based on discharges taken at all stages of the river after Harlacher's method, using ·85 as the constant.

The following note on *Dredging* has been kindly written for me by Mr. Philpotts, manager of the Egyptian Dredging Company :—

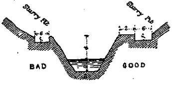
"*Bucket Dredgers* work well in hard sand, mud, and anything except stiff sticky clay or hard virgin earth, provided the buckets are of good shape, and so much depends on this, that with a bad shaped bucket working in sand, a number of buckets will remain full till after passing the shoot, and the contents will be returned again to the canal. The buckets should be made with plenty of taper in every direction. These dredgers are much heavier than either sand or grab dredgers and must necessarily draw much more water, which prohibits their use in the smaller canals or drains, but when they can be used they are much more efficient for earth or mud, both as regards output and duty.

Centrifugal Sand or Mud Pump Dredgers work well in any sort of soft mud or sand. They require a considerable amount of attention on the part of the operator to ensure the delivery of a good thick mixture of sand and water, otherwise there would be a loss of fuel in simply pumping water instead of mud or sand. The efficiency is greatly increased by the application of an arrangement of steel cutters working round the outside of the suction nozzle, and the dredger slewed regularly from side to side of the canal with light chains driven by worm gearing.

The water pumped is generally between eight to ten times that of mud or sand. The average lift is 3 to 4 metres.

A 12-inch pump requires an engine which will indicate from 35 to 40 horsepower.

In the first kilometre of a canal it pays to dredge the silt into hopper barges and drag them out into the Nile and there discharge the material. Elsewhere a long couloir deposits the material into slurry pits, dug annually on the berm. In some cases, where the berm is far off, the bucket dredgers lift the silt into barges, from which it is pumped over the banks by sand pumps. The grab dredgers deposit into the slurry pits on the berm. With the sand pump long trenches are dug on the berm, and the silt and water combined is pumped into them; as the water moves along it leaves all the silt behind, and the water is eventually taken back into the canal through a pipe at the end of the trench. These trenches should be about 500 metres long each, and well retired from the edge, or the percolation and infiltration of the water make the berm slip into the canal. The water should always return to the canal in front of, and not behind, the dredging.



The Grab Dredgers can work in almost any kind of soil, whether hard or soft, by

the use of suitable grabs. There are about four different types of grabs in common use with these dredgers. They are useful for deepening or widening canals in original soil under water, removing stones from sudds, and for weed clearing. They take up little room and can be mounted on pontoons designd for light draft of water, consequently can follow a winding canal.

These dredgers are necessarily slow working, while the wear and tear is excessive owing to the varying strains brought on the machine by the sudden release of the load suspended from the end of the jib."

The Government rate for dredging is 3·40 piastres per cubic metre.

The more important points in a number of *specifications* written by Colonel Western and Mr. Reid are given here for reference :—

Lock Gates.

Wrought Ironwork.

To be of dimensions figured on the drawings. All angles of girders to be of best girder angles, of single lengths, without joints. All plates of girders to be of the longest lengths obtainable, and no single plate to be less than $10' = 3·048$ metres long. Where joints in webs are needed, such joints to be double covered with cover plates of $\frac{5}{16}$-inch iron, with two rows of rivets $3'' = ·076$ metre pitch on each side of joint. Rivet holes to be truly set out and cleanly punched. All rivets in welts of heel-post, along heel-post vertical girder, and along bottom girder of each gate, to be countersunk and flush-headed on outer face, so as to permit of the sheeting of the gate lying in close contact with the sill and quoin everywhere. All other rivets to be snap-headed, and no flawed, cracked or split rivets to be allowed to remain in the gate. All cranking of angles to be well and truly forged, and no cracked or reedy angles to be put into the works.

The sheeting of the gates and the webs of the girders to be of the best girder plates. The sluices on the gates to fit truly and well on to cast-iron fitting strips, planed on face, and attached to the gate by countersunk bolts nutted up from the inside. All rivets of sluices to be flush on the face next the gate.

The heel and baling pins to be of Bessemer steel, turned and wrought to the dimensions shown on the drawings. The heel-pin to be shaped to the curve known as the "Equitangential tractrix." Length of generating tangent to be 4 inches, and pivot to be 7 inches long, curve commencing 1 inch from the apex. The bearing blocks of both pins to be cast to their true shape and chilled on their bearing surfaces, the pins being then wrought to fit them an easy sliding fit, and tempered to medium hardness. The sluice lifting gear to be as shown on drawings, to be well made, and to work easily and smoothly, without backlash or play, other than the fair clearance of teeth. The blocks holding the lifting rods to be bored to fit the rod, and to be attached to the gate with their centres in a truly straight line.

The whole gate to be built in a good, workmanlike manner, of good material, well put together, with all joints butting closely and evenly.

Woodwork.

All woodwork to be of teak, sound and well seasoned, no scarf to be less than 1 metre in length in the mitre post, and single lengths to be used for bottoms and tops of lock gates.

Cast Ironwork.

Quoins, Cills, Grooves, &c. All cast ironwork to be of best grey iron, soft, clean, and free from blow-holes, cracks, warps, or other blemish. The faces of the cills, where the gates bear against them, to be planed for a depth of 8″ = ·203 metre from their upper faces; the ends of the cills where they meet the quoins to be also planed to make a true joint. The upper faces to be planed on a width of ½ inch so that a water level may be moved along the cill to test its being truly horizontal when in position. The quoins where they bear against the cills to be planed, as also the chipping strips on which the gates bear when closed. The latter (chipping strips) to be scored down their entire length with one line each; such lines to be truly parallel to the axis of the quoin, and exactly at one quadrant's distance from one another. The blocks carrying the pivot and baling pin to be faced to the curvature of the quoins, the quoins themselves being also truly faced where the blocks bear. The ends of each piece of the quoins to be planed truly square to its length, so that the complete quoin shall be truly straight without the employment of packing of any kind.

All bolt-holes to be truly placed, so that no difficulty may arise in erecting.

Gearing.

The opening and closing gear for the lock gate to be as shown by the drawings. The winches to be well made and to work smoothly in all their parts.

The roller boxes for the opening chains to be as shown on the drawings, and to have each roller capable of being taken out and replaced without disturbing the box. All spindles of rollers to be of steel, hard tempered on their wearing surfaces. Bearings of rollers in boxes to be chilled. All bearings in winches to be bushed with phosphor bronze bushes ⅜-inch thick, and all shafts to be of steel.

All necessary chains to be supplied and fitted, and to be of best-best, tested, close link, crane chain.

WELL-SINKING.

Before commencing work, lining-out pillars should be built for at least two faces at right angles to one another, and from these lines all measurements throughout progress of work should be made.

Curbs for blocks should be laid at lowest possible level and sunk into soil at least 20 centimetres before brickwork steining is built upon them.

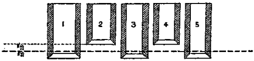
The whole of the brickwork, permanent and temporary, necessary for the sinking of a block, should if possible be built before sinking is commenced. Blocks should be left to set for one week after completion of last course of permanent brickwork, before the dredger is allowed to be put down.

The exterior of blocks should be smooth and true, the interior as rough as it is possible to make it.

In sinking a line of blocks, alternate blocks to be sunk together. When these have been sunk to a depth of 25 centimetres *below* the required depth, the remaining blocks to be sunk and to be taken down to 25 centimetres *above* the required depth.

On the completion of sinking of each individual block, a plug of 75 centimetres of cement concrete and then 75 centimetres of ordinary concrete to be lowered into the well.

This plug should be allowed to set for 10 days, and then water carefully baled out and the well filled with concrete to the necessary height by layers. No bank or



spoil should be allowed nearer to the blocks at level at which curbs are placed than 2 metres at a minimum. On completion of sinking of three adjoining blocks, the space between the two farthest from sinking in progress to be piled up and down stream, joint cleared of sand to level of curb by means of long-handled small-pattern "phaorahs" * or scoops, and space filled with concrete. It is almost impossible in most cases to lay this dry, and had best not be attempted.

The pump for drying concreting area should be placed in one of the foundation blocks in a side wall—not in one of the up or down stream curtains. This pump-well must have a good solid plug at its bottom, so that all water pumped may be from concreting area.

To admit the water to the pump, the wall of block may be cut through, and when work is completed and pump withdrawn, the block and wall knocked down and filled with concrete in the usual manner. The excavation for talus under this system, must be done whilst pump is working for the concreting area.

The concreting must be commenced from the end of work farthest from pump, and should work in layers towards it.

No spring whatever is admissible through the concrete or its joints, and if such appear the work should be taken up and redone.

For the better checking of depths in well sinking, it is usual to make a plaster gauge on one face of a block, marked by cross cuts at every half metre. By mere reading of these gauges the relative position of all wells can be easily ascertained, when water level or top of one well only has been levelled. It is also usual to number all wells, and to record the depths sunk daily or weekly by the numbering.

In making curbs the maximum slope possible should be given to the under side, so as to make as good an outside cutting edge as possible.

* Indian term.

The following "Instructions for Bidders," "Form of Tender," and "Specification" for the Zargoun syphon are good specimens of the recent practice of the Ministry of Public Works:—

MAHMUDIA CANAL.—ZARGOUN SYPHON.

Instructions for Bidders.

Adjudication on Wednesday the 18th January, 1888.

Ministry of Public Works,
Director-General of Works.

1. All tenders must be made in duplicate on government stamped paper, in accordance with the annexed form of tender, enclosed within two envelopes. The outer will be addressed to the Director-General of Works, and on the inner will be inscribed:

"Tender for the works of the Zargoun Syphon—Mahmudia Canal."

2. To the tender will be attached a certificate of a deposit of 100*l.* (one hundred pounds Egyptian) for the complete works in accordance with Art. 4 of the general clauses and conditions.

3. The prices will be written in letters and in figures.

4. The general conditions of the contract will be those in use at the Ministry of Public Works.

5. The contractor will be fined 2*l.* (two Egyptian pounds) for each day of delay after the date agreed upon in the contract for the completion of the work.

6. Specimens of the materials to be employed must be submitted to the Director-General of Works within five days of the acceptance of the tender, and before the signature of the contract.

7. After the signature of the contract, the contractor will not be permitted to take a partner without the permission of the Ministry.

8. The Ministry of Public Works reserves to itself the right to reject any or all the tenders, without having to give any reasons for its decision.

9. Payments will be made monthly, and as soon as possible after the first day of the month.

10. Bidders are invited to attend at the opening of the tenders.

Form of Tender.

Adjudication of the 18th January, 1888.

The undersigned ———, a ——— subject, resident at ———, engages himself to the Minister of Public Works to supply all the materials and execute all the works for the syphon and the diversion near Zargoum, in accordance with the designs, specifications, and other pieces of the project, of which he acknowledges having taken full and complete cognisance, at the prices entered below:—

—	Syphon and Diversion, Rate in piastres Tariff	
	In Letters	In Figures
Excavation and filling (lump sum)		
„ of diversion per metre cube . . .		
Concrete per metre cube		
&c.		

The undersigned binds himself to commence the works on the outside within ——— days of the signature of the contract, and to complete them within ——— months of the same date.

Cairo, the ———

SPECIFICATION.*

Description of Works.—The works to be executed consist of a syphon provided with two wrought-iron pipes of 1·56 metre diameter, with stiffeners, and the earthwork of the diversion, and the up and down stream approaches.

General.—The work to be constructed and completed in accordance with the rules of art, in conformity with the drawings, and in accordance with the instructions of the Director-General of Works.

The axes of the work will be traced on the ground by the engineer delegated by the Ministry to superintend the work, and a bench mark will be fixed by him to serve as a basis for determining levels of foundations, floors, &c. The contractor to furnish the workmen, materials, and instruments necessary for the engineer in charge to check the levels, widths, &c., of the work, whenever he may judge necessary. The contractor to make all arrangements at his own cost for the land needed for the execution of the work, and he will be responsible for all or any accidents which may happen during the execution of the work. The sheet piling or other protective works which may be necessary will be equally at the charge of the contractor.

None of the foundation works in concrete, masonry or pitching, to be commenced without the permission in writing of the engineer in charge; and in order to obtain this permission the contractor must give eight days' notice before the probable date on which he will commence his work.

Earthwork.—All the earthwork necessary for the execution of the masonry works will be paid for by a lump sum, and to include excavation and filling, as well as the transport and the levelling of excess earth, up to a maximum distance of 100 metres from the centre line of the work, in conformity with drawings and written instructions of the engineer in charge. Will be considered as earthwork necessary for the masonry work, and included within the lump sum, all the earthwork between

* All the original documents are in French, and as they have been translated by me, I am responsible for any errors.

the outer edges of the pitching of the up and down stream approaches. The amount of earthwork at a lump-sum contract is approximative, and must be verified and accepted by the contractor at his risk and peril.

The earthwork of the diversion and its banks will be paid for by the metre cube, and in order to facilitate the measurement, sections of the natural ground will be left at the points indicated by the engineer in charge. The bottom of the excavation for foundations to be dressed off horizontally, in accordance with the plans; all excavation in excess to be refilled with brick masonry or concrete at the contractor's cost.

The filling in behind the masonry work will be carefully made in successive layers of ·50 metre, watered and rammed. They will be raised in the same measure as the masonry, and must never be more than 2 metres below the level of the masonry. All the earth in excess will be placed according to the plans and the written orders of the engineer in charge, and carefully dressed.

Ordinary Concrete.—The ordinary concrete used in the foundations of the masonry work and for the syphon will be composed of 1 part mortar and 2 parts ballast, measured dry. The ballast will consist of hard stone or well-burnt brick; 80 per cent. must be able to pass through a ring ·025 metre diametre, and the rest, or 20 per cent., through a ring ·015 metre diameter. The ballast must be well washed, and must be soaked in clean water for at least twelve hours immediately before it is used. The mortar will be composed of 1 part of freshly burnt and slaked lime and of 1½ parts of pounded bricks passed through a sieve of ·001 metre. The ballast will be evenly spread over a clean area; to the ballast will be added in the prescribed proportion the mortar, previously mixed dry. The whole will be turned at least twice over by a shovel whilst the necessary water is added. After this mixture the concrete will be immediately used, and for no reason will a delay of more than two hours be permitted between the times of mixing and employing.

Each layer of concrete must not exceed ·15 of a metre, and it must be rammed with iron rammers until it attains a thickness of ·11 of a metre. All surfaces must be clean and constantly watered. Before spreading a fresh layer the preceding one must be scrabbled.

Brick Masonry.—The bricks to be of good quality, with regular faces, and well burnt; when immersed in water for twelve hours the weight of water absorbed must not exceed one-eighth of the weight of the brick when dry. The bricks to be immersed in clean water for at least twelve hours immediately before being used. A sample of these bricks must be deposited at the office of the Director-General of Works. They will be set in mortar composed of 1 part of freshly burnt and slaked lime and 1½ parts of pounded brick, or "humra." All "humra" employed on the works will be composed solely of clay balls or bricks well burnt,* so that after twelve hours of immersion in water they do not absorb more water than one-eighth of their own weight when dry. The mortar will be mixed in a mortar-mixing machine with the necessary quantity of water. On no account will any but recently made mortar be used. Neither brickbats nor cracked bricks must be used for filling without the written permission of the engineer in charge. All the courses must be perfectly level. Bricks of ·11 metre × ·05 metre × ·22

* Ordinarily underburnt bricks are used, though well-burnt bricks are specified, as it is dangerous to specify underburnt bricks.

metre will be used by preference, and in such a manner that 1 metre in height will contain 18 courses. The dimensions of the bricks, however, may be changed with the written permission of the Director-General of Works.

English bond will be used whenever possible. Each brick will be placed on a bed of mortar and pressed home so that all the joints are filled, and on no account will the mortar be introduced afterwards. No part of the masonry must be more than 2 metres higher than the neighbouring parts, and the connecting slopes must be 2 to 1.

Brick Floor.—The part of the floor in brickwork will be set in mortar composed of 1 part of Portland Cement (English) and 2 parts of coarse sand, angular and washed, unable to pass through a sieve of ·001-metre meshes. The sand to be clean and to contain no foreign matters. The Portland Cement to be of a good mark, and to resist a tension of 30 kilogrammes per (·01 metre × 0·1 metre) square centimetre after seven days' immersion.*

Ashlar.—The ashlar in the top courses of the walls to be of the best quality of Tourah or Abassiah stone, of an exact height, with well-dressed faces. Their cubic contents not to be less than ·90 metre × ·60 metre × ·40 metre. The thickness of the joints not to be over ·015 metre or less than ·007 metre. The mortar to be composed of 1 part of cement and 2 parts of sand.

Pointing.—All exposed faces of walls to be pointed with Portland cement mortar composed of 1 part cement and 2 parts of coarse sand, angular and washed; before pointing, the joints to be raked out to a depth of ·02 metre and well washed. The pointing to keep pace with the masonry, and to be done while the mortar in the joints is still fresh and has not set. The cost of the pointing to be included in the cost of the brick masonry and the ashlar work.

Pitching.—The rubble pitching to be obtained from the Tourah or Abassiah quarries, and the blocks to weigh 50 kilogrammes each as a mean, no block to weigh less than 30 kilogrammes. The face stones will be carefully placed by hand, and the interstices filled with splinters or small pieces of stone.

General.—The faces of the masonry to be carefully built, and kept clean, and the unfinished parts to be constantly watered. The iron pipes not to be put in position except in the presence of the engineer in charge. The contractor to inform the engineer in charge beforehand of the date on which he will be ready to put each pipe in place. No complaint will be entertained of a delay to the work owing to the inability of the engineer to assist immediately.

No extra payment will be made for the putting in position and fixing of the iron pipes. The lime to be made of Tourah stone, and to be burnt and slaked on the works.

Wrought-iron Pipes.—All ironwork to be of the best quality, and of the dimensions figured on the drawings. All plates, angles, and cover plates to be of single lengths. All joints in the plates to be alternately on the right and left of the pipes, exactly opposite each other on the same plane. The joints in the cover plates to fulfil the same conditions on a plane perpendicular to the last. All joints to be single covered on their outer surface, with cover plates of the same thickness as the plates, i.e. inch, on a width of 6 inches. The diameter of rivets to be $\frac{3}{4}$ inch,

* This answers for small quantities of cement.

and pitch 3 inches. The ⊥-iron stiffeners to be 4 inches × 2 inches × ½ inch, with rivets ½ inch diameter and 3 inches pitch. Rivet holes to be truly set out and cleanly punched. The rivets are to be snap headed, and no flawed, cracked, or split rivets to be allowed to remain in the pipes. The contact between the plates and cover plates, or plates and stiffeners, to be perfect. All the angle irons to be well and carefully forged, and no cracked or reedy angles to be put into the work. The whole pipe to be built in a good, workmanlike manner, of good material, well put together, with all joints butting closely and evenly. The inner and outer surface of the pipes to be painted with two coats of tar before leaving the shops, but not before they have been inspected by the engineer in charge, or some other person delegated by him for this purpose.

Dredging.

In contracts for dredging there are certain points which cannot escape observation, but there are others also which by experience have been found to be of extreme importance, and which should always be entered in the contract. The following come within the first category :—Length of contract; means of execution, whether by existing Government plant or by plant to be purchased by the contractor. If the former, terms of maintenance. How the dredged material is to be disposed of. How the work is to be measured: ordinarily by soundings in front of and behind the dredger; with the maximum and minimum intervals of time between which the two measurements are to be made. If Government dredgers, Government emyloyés in the service of the contractor. Deposit. Mode of execution. Contractor not to be asked to dredge less than 50 centimetres in depth. Maximum and minimum quantities of work. Service orders may be changed by giving three weeks' notice. Action of Government in case of failure of contractor to do the requisite quantity of work in the requisite time. Price per cubic metre if below minimum; above maximum and within the minimum and maximum. How payments are to be made. Maximum height of spoil banks and berms. Minimum width of opening in bridges. Times within which dredging is to be done. Short curves on canals. Trees. Persian wheels on banks. Navigation. Landslips. Tolls on canals. Minimum and maximum widths of canals and depths of water. Date on which Government to inform contractor of the probable work to be done in coming year. "Force majeure."

The points, however, which should not be omitted in a contract are the following:—(1) A very *exact* definition of the expression, "failure of contract." (2) Liberty for the Government to dispense with dredging in any or all the canals in case of extraordinary deposits, or necessity to clear quickly by hand labour; a good plan is to agree to pay the contractor a fixed sum annually by monthly instalments, and a low rate for work done below a certain fixed quantity; if the work exceeds this quantity, the full rate to be paid: e.g. a yearly clearance of 500,000 cubic metres is anticipated at ·04*l.* per cubic metre, the fixed sum to be paid annually would be 10,000*l.*; the price per cubic metre under 500,000 cubic metres would be ·02*l.* per cubic metre; and above 500,000 cubic metres, ·04*l.* per metre. The contractor on his part would supply the material necessary to dredge a certain quantity per month, and keep it in perfect order, ready to work. This would eliminate many difficulties. (3) If Government plant is supplied, it should be carefully specified beforehand as to how the terms of the contract are modified, or

not modified, by the inability of the dredgers to do some kinds of work which become necessary, owing to excess of berm in places, or shortness of couloir, &c. (4) It should also be specified that the material excavated belongs to Government, and must be placed where required by Government. Owing to want of some term like this, the contractors on some canals sell the material excavated, while the berms which need improving or the canals which need contracting cannot be improved.

Earthwork by Hand.

In work of this kind, on canals which are closed for a fixed time for clearance, and on whose prompt clearance and reopening the existence of expensive crops depends, it is always necessary to add a clause to the effect that if at any stage of the work the engineer in charge considers that the contractor is not working sufficiently fast to finish the work within the specified time, he may take away from the contractor the whole, or part of the work, and give it to another contractor, or do it by hand labour, on certain conditions; without appeal on the part of the contractor.

Rates of Work.

The following were the rates of materials at the Barrage:—

Concrete metal	£·330 per cubic metre.
Desert sand	·128 „
Lime	·420 „
Pounded brick	·410 „
Tourah ashlar	3·500 „
Trieste „	6·600 „
Rubble stone	·330 „
Coal (1888)	1·450 per ton.
Sacks for earth	·025 each.
Cement	·533 per barrel (11 barrels = 1 cubic metre.)
Earthwork	·023 to £·045 per cubic metre.
Filling, sewing, and throwing sacks into place	·0125 each.

The ordinary prices of labour are:—

Navvy	£·04	per day.
Italian mason	·25 to £·40	„
Egyptian mason	·10 „ ·18	„
Italian carpenter	·25 „ ·40	„
Egyptian carpenter	·08 „ ·18	„
European blacksmith	·20 „ ·40	„
Egyptian „	·08 „ ·20	„
European moulder (1st class)	·50 „ ·60	„
„ „ (2nd „)	·25 „ ·40	„
Native „	·15 „ ·25	„

European fitter (1st class)	£·40 to £·60 per day.		
" " (2nd ")	·25 "	·40	"
Native "	·15 "	·25	"
Pattern maker	·30 "	·45	"
European turners	·40 "	·50	"
Native "	·20 "	·30	"
European boiler-makers	·30 "	·50	"
Native boiler-maker	·20 "	·25	"
Native riveters	·12 "	·20	"

The mean *prices* of *work* are as follows:—

Dredging from	£·030 to £·040 per cubic metre.			
Wet clearance by hand from	·012 "	·060	"	
Dry earthwork "	·011 "	·040	"	
Brick masonry in lime	1·00 per cubic metre.			
" in cement	1·50	"		(mortar, 2 sand, and 1 cement.)
Lime concrete	1·20	"		
Cement concrete	2·10	"		(5 metal, 2 sand, 1 cement.)
Tourah ashlar	3·75	"		
Trieste "	7·00	"		
Teak wood	1·00 per cubic foot (as in gates.)			
Wrought iron	24	per ton (lock gates.)		
Cast iron	16	"		(lock cills and quoins.)
Rolled beams	9·50	"		
Cast-iron grooves in quantities	9·50	"		

In making estimates of lock gates and regulating gates, the following prices may be roughly taken per square metre of opening:—

Two pairs of lock gates (including iron cills, quoins, &c.)	£22 per square metre of opening.*
Regulating gates (including grooves, lifting gear, &c.)	£9 " " "

Piles 6 metres long and 12 in. by 5 in. in section cost	£·42
Cost of driving (ringing engine)	·25
Repairs and filling	·03
	£·70 per pile.

Guide piles, 12 in. by 12 in. section, put in at every 12 ft., say cost 1·35*l*., so that 100 metres in length of 6-metre long piling would cost 250*l*.

Well sinking costs 5*l*. per metre, measured vertically on the well.

The following two selections from the Irrigation Report for 1887, the first written by Mr. Wilson and the second by Major Brown, give the details of work in an ordinary year.

* Square metre of opening is obtained by multiplying width of lock by height of lock wall above floor. The price per square metre of gate (including cills, quoins, gearing, &c.) is 11*l*.

" *Upper Egypt.*—The total quantities of earthwork executed during the year are as follows :—

Circle	By Hand		Dredging	
	Quantity	Cost	Quantity	Cost
	cubic metres	£	cubic metres	£
Fourth Circle	6,079,832	71,940	214,212	8,196
Fifth "	2,938,045	31,752	..	..
Girga Directorate . .	1,867,490	23,089	..	..
Total	10,885,367	126,781	214,212	8,196

The average cost of the work done by hand was 1·16 piastres * per cubic metre. The above includes some new channels and banks, and some improvements that will be noted in the following section.

Owing to the large quantities of earthwork in the new drains in Lower Egypt, much labour was attracted there from Upper Egypt, and in June and July some difficulty was experienced by the contractors in keeping their labourers.

Considerable economy has been effected by reducing silt clearance in the Girga Directorate and Fifth Circle, both Mahmud Bey Sidky and Mohamed Bey Sabry having interested themselves greatly in this. The first point to attend to is to reduce the deposition of silt by keeping the upper regulators in a canal fully open in the early part of the flood, so as to maintain as high a velocity as possible in the canal and carry the silt on to the basins. The second point is not to clear any silt uselessly. The bed-widths given in the 'Notes' by the late Colonel J. C. Ross are calculated on the assumption that the side slopes are one to one, but in some of these canals the side slopes are three to two or even two to one. In such canals it is evident that the width of bed may be reduced without reducing the area of waterway below that of the theoretical section with steeper side slopes.

There are other canals, too, that were originally dug wider than required under the remodelled system. The upper part of the Um El-Tubul Canal, for instance, was originally dug with a 12-metre bed, but is now cleared to a 5-metre bed only. It is obvious that, if the present bed is 50 or 60 centimetres above the theoretical bed which is calculated five metres wide, the waterway of the channel will still be larger than theoretically necessary. By useful attention to such details the clearances will be still further reduced. It is to be remembered that not only has every cubic metre of silt that is removed from a canal to be paid for, but it goes to widen the spoil banks and to cover good land.

The Ramadi Canal, the head of which was altered two years ago with a view of reducing the heavy silt deposit that occurred in it, shows less silt clearance than it used to.

The remodelled part of the Rannan Canal receives a very heavy silt deposit every year and it may be necessary to re-open the old head. The silt in the existing head is coarse sand, while the spoil banks of the old channel show fine mud and clay.

* 1*l.* = 100 piastres.

In river protection works in the Fourth Circle, 14,211 cubic metres of stone were used at a cost of 1733*l.* The old spurs were repaired and strengthened and eight new spurs were made.

To facilitate and improve irrigation, forty-five new masonry works were built during the year; thirty-five, costing 20,140*l.* in the basins, and ten, costing 953*l.*, in the perennially irrigated tract.

The quantity of earthwork in new channels and banks was as follows:—

	cubic metres
In Fourth Circle	382,911
In Girga Directorate	133,001
In Fifth Circle	180,590
Total	696,502

The length of banks revetted with stone was 26,881 metres; 40,147 cubic metres of stone were used at a cost of 10,595*l.*, of which 3258*l.* was expended in collecting stone in 1896. In addition to this a sum of 4425*l.* was expended in collecting stone for work to be done in 1898. The average quantity of stone used per kilometre of revetted bank was 1493 cubic metres, and the average cost was 394*l.* per kilometre.

An Inspection House was built at Maghaghah for 250*l.*, and two small rest houses were built on the Bahr Yusuf for 198*l.*

A sum of 112*l.* was spent on repairs of buildings.

During the year thirty-five regulators were remodelled at a cost of 7972*l.*, the vertical needles by which they used to be closed being replaced by horizontal planks working in iron grooves. It is satisfactory to note that there are only eight regulators remaining to be remodelled in Upper Egypt, and these will be completed before the next flood.

In the Fourth Circle iron grooves were fitted in the only four regulators that had grooves of brickwork.

The regulators built and remodelled previous to 1894 have grooves of ashlar stone, and owing to the roughness of the stone great difficulty is experienced in putting down and removing the planks when there is a considerable head of water on the regulator. During the year angle irons 6 inches × 4 inches × ½ inch were fitted over the downstream edges of the grooves of four regulators. The angle iron on a groove is in one length, and the sleepers bear against the 4-inch face. It is necessary to dress the stone carefully so that the angle iron fits properly on it. The cost is about 55 piastres per metre run of groove. A considerable saving in labour during the flood resulted in the four regulators fitted in this way, and other regulators will be similarly fitted.

4763*l.* were spent on repairs of bridges, painting gates, &c., &c.

Masonry blocks, with their surfaces at the correct bed level of the channels, were built at kilometre intervals in the canals. They save the engineers a great deal of work in levelling, especially in canals in which there is no silt and in which the bed blocks can be seen when riding along the banks.

In the Fayum Province eighty-two kilometres of new roads were made, thus completing the whole of the system of 169 kilometres which were included in the last Decree.

The amount paid during the year was 3413*l.*

The total cost of all the roads now existing in the province is as follows:—

First system of roads	150½ kilometres, costing	£11,448
Second system of roads . . .	169 "	19,602
Total	319½	£31,051

or 97·2*l.* per kilometre, including cost of land and all charges.

A concession has been granted to the Fayum Light Railway Company to construct 150 kilometres of railway lines on the existing roads; the surveys have been submitted, and construction should begin during 1898.

On repairs and maintenance of the roads 682*l.* was spent, being 2·9*l.* per kilometre on 237 kilometres of roads.

In the Asyut Province no agricultural roads have been made; a project was drawn up some years ago, but the Provincial Council rejected it.

The total length of agricultural roads completed up to the end of the year is as follows:—

	kilometres
In Fayum Province	319½
In Beni-Suef Province	104
In Minia Province	87
Total	510½

No expenditure was incurred during the year on bridges to replace ferries. There is a balance unspent of 266*l.*, which will be utilised during 1898.

The expenditure during the year was as follows:—

Establishment and contingent charges	£32,428
Works	221,199
Total	£253,627

EARTHWORK, UPPER EGYPT, 1897.

Provinces	Repairs to Banks	Clearance of Flood Canals and Drains	Clearance of Perennial Canals	Clearance of Perennial Drains and New Drains	Closing Cuts	Dams in Canals	New Canals and Banks	Repairs to Agricultural Roads	Total	Cost
	cubic metres	cubic metres	cubic metres	cubic metres	cubic metres	cubic metres	cubic metres	cubic metres	cubic metres	£
Fourth Circle	2,280,319	700,645	1,830,310	405,376	141,458	..	811,966	123,970	6,294,044	80,136
Girga Directorate	838,047	1,892,965	..	..	24,487	13,444	169,103	..	2,938,045	31,752
Fifth Circle	415,136	1,314,304	..	..	12,882	..	182,301	..	1,867,490	23,089
Total .	3,533,502	3,907,914	1,830,310	405,376	178,827	13,444	1,163,378	123,970	11,099,579	134,977"

"*Lower Egypt.*—The quantities and cost of earthwork executed by hand, in the ordinary maintenance of canals, banks and drains, were as follows:—

—	Cubic metres	Cost, £	Mean Rate
First Circle	3,031,118	46,686	1·54
Second Circle	2,684,182	53,096	1·98
Third Circle	2,024,108	31,171	1·54

The maintenance of drains is naturally becoming a heavier item of expenditure every year, and the increase is rapid owing to the great development that has and is taking place in the drainage system of Lower Egypt. And it would be well for the efficiency of the drains if we could afford to spend still more on their maintenance. In the Third Circle also the increased expenditure in pumping at Mex causes a serious diminution in that Circle's resources.

The quantities dredged during the last four years in Lower Egypt are given in the following table:—

Canals and Drains	Quantities Dredged			
	1894	1895	1896	1897
First Circle.				
Canals	532,000	674,000	478,000	659,000
Drains	16,000	129,000	140,000	147,000
Total	248,000	803,000	618,000	806,000
£	20,000	30,000	26,000	29,000
Second Circle.				
Canals	188,000	359,000	201,000	210,000
Drains	..	165,000	46,000	243,000
Total	188,000	524,000	247,000	453,000
£	7,000	19,000	9,000	16,000
Third Circle.				
Canals	514,000	419,000	274,000	325,000
Drains	..	..	..	15,000
Total	514,000	419,000	274,000	340,000
£	?	?	?	12,000
Total Lower Egypt	1,250,000	1,746,000	1,139,000	1,599,000
£	?	?	?	57,000

The sums spent in repairing old spurs and revetments and in doing new work of this description, and also in purchasing sacks and timber and paying for hire of boats were as below :—

First Circle	£7,000
Second Circle	10,042
Third Circle	8,814
Total	£25,856

The following statement records the progress in agricultural roads :—

Circle and Province	Existing up to End of 1897	Added during 1897	Total Existing at End of 1897
First Circle.			
Kaliubiyah	34	..	34
Sharkiyah	177	..	177
Dakahliyah	142	..	142
Second Circle.			
Menufiyah	230	3	233
Gharbiyah	242	64	306
Third Circle.			
Beherah	240	41	281
Total	1065	108	1173

In the First Circle a sum of 1260*l.* was spent in keeping the existing 353 kilometres of roads in repair.

In the Second Circle 67 kilometres of new roads were made and 11,343*l.* expended on this account. A further sum of 884*l.* was spent in repairs to the previously existing 472 kilometres of roads.

In the province of Beherah, Third Circle, 41 kilometres of new road were made and 3258*l.* expended; and in addition 500*l.* on repairs to 65 kilometres out of a total existing length of 240 kilometres.

The state of repair in which these roads are kept is not all that could be desired; and the reason is this. Inspectors of Irrigation have so much other work of greater urgency on their hands to occupy their time and attention, and so many demands on account of irrigation and drainage necessities to exhaust their budget allotments, that the roads have to be left to the care of district engineers. In the interest of those who use the roads it would be better to have a Road Department with its own budget allotments for road maintenance, for there are now 1173 kilometres of road existing in Lower Egypt and more are being constructed.

In the Second Circle two iron lift bridges to replace ferries were made from the ferry fund, one at Nabaroh on the Bahr Shibin at a cost of 2083*l.*, and the other at Kasta on the Kodabah Canal.

In the Third Circle a contract was given out for an iron swing bridge at Kafr Daûd, over the Khatatbeh Canal, to cost 1462*l.*

Bridges to replace ferries on the Mahmudiyah Canal have been asked for, but, as the boat traffic along the canal is far more important than the land traffic across the canal, it would be better to provide for the latter by establishing improved ferries and so avoid introducing any new obstruction to the navigation, as enough exist already.

The light railway from Mansurah to Menzaleh and Matariyah was opened in August, and its branch from Mehallet Damana to Tanah in September.

The lines from Mansurah to Mit Ghamr, from Mit Ghamr to Simbellawin, and from Simbellawin to Mit Samanud are well advanced.

The Damanhur-Delingat line is in a forward state, 21 kilometres out of a total of 25 having been constructed up to the end of 1897. The Damanhur-Hosh Issa line also was commenced."

The following two tables for converting cubic metres per second into cubic metres per day, and cubic metres per day into cubic metres per second, will be found convenient.

TABLE FOR CONVERTING CUBIC METRES PER SECOND INTO CUBIC METRES PER DAY.

Cubic Metres per Second	Cubic Metres per Day	Cubic Metres per Second	Cubic Metres per Day	Cubic Metres per Second	Cubic Metres per Day	Cubic Metres per Second	Cubic Metres per Day
1	86,400	26	2,246,400	51	4,406,400	76	6,566,400
2	172,800	27	2,332,800	52	4,492,800	77	6,652,800
3	259,200	28	2,419,200	53	4,579,200	78	6,739,200
4	345,600	29	2,505,600	54	4,665,600	79	6,825,600
5	432,000	30	2,592,000	55	4,752,000	80	6,912,000
6	518,400	31	2,678,400	56	4,838,400	81	6,998,400
7	604,800	32	2,764,800	57	4,924,800	82	7,084,800
8	691,200	33	2,851,200	58	5,011,200	83	7,171,200
9	777,600	34	2,937,600	59	5,097,600	84	7,257,600
10	864,000	35	3,024,000	60	5,184,000	85	7,344,000
11	950,400	36	3,110,400	61	5,270,400	86	7,430,400
12	1,036,800	37	3,196,800	62	5,356,800	87	7,516,800
13	1,123,200	38	3,283,200	63	5,443,200	88	7,603,200
14	1,209,600	39	3,369,600	64	5,529,600	89	7,689,600
15	1,296,000	40	3,456,000	65	5,616,000	90	7,776,000
16	1,382,400	41	3,542,400	66	5,702,400	91	7,862,400
17	1,468,800	42	3,628,800	67	5,788,800	92	7,948,800
18	1,555,200	43	3,715,200	68	5,875,200	93	8,035,200
19	1,641,600	44	3,801,600	69	5,961,600	94	8,121,600
20	1,728,000	45	3,888,000	70	6,048,000	95	8,208,000
21	1,814,400	46	3,974,400	71	6,134,400	96	8,294,400
22	1,900,800	47	4,060,800	72	6,220,800	97	8,380,800
23	1,987,200	48	4,147,200	73	6,307,200	98	8,467,200
24	2,073,700	49	4,233,600	74	6,393,600	99	8,553,600
25	2,160,000	50	4,320,000	75	6,480,000	100	8,640,000

TABLE FOR CONVERTING CUBIC METRES PER DAY INTO CUBIC METRES PER SECOND.

Cubic Metres per Day	Cubic Metres per Second	Cubic Metres per Day	Cubic Metres per Second	Cubic Metres per Day	Cubic Metres per Second
10,000	0·1157	750,000	8·6805	5,000,000	57·8704
20,000	0·2315	800,000	9·2593	5,250,000	60·7639
30,000	0·3472	850,000	9·8380	5,500,000	63·6574
40,000	0·4630	900,000	10·4167	5,750,000	66·5509
50,000	0·5787	950,000	10·9954	6,000,000	69·4444
60,000	0·6944	1,000,000	11·5741	6,250,000	72·3380
70,000	0·8102	1,250,000	14·4676	6,500,000	75·2315
80,000	0·9259	1,500,000	17·3611	6,750,000	78·1250
90,000	1·0417	1,750,000	20·2546	7,000,000	81·0185
100,000	1·1574	2,000,000	23·1481	7,250,000	83·9120
150,000	1·7361	2,250,000	26·0417	7,500,000	86·8055
200,000	2·3148	2,500,000	28·9352	7,750,000	89·6991
250,000	2·8935	2,750,000	31·8287	8,000,000	92·5926
300,000	3·4722	3,000,000	34·7222	8,250,000	95·4861
350,000	4·0509	3,250,000	37·6157	8,500,000	98·3796
400,000	4·6296	3,500,000	40·5092	8,750,000	101·2731
450,000	5·2083	3,750,000	43·4028	9,000,000	104·1667
500,000	5·7870	4,000,000	46·2963	9,250,000	107·0602
550,000	6·3657	4,250,000	49·1898	9,500,000	109·9537
600,000	6·9444	4,500,000	52·0833	9,750,000	112·8472
650,000	7·5231	4,750,000	54·9768	10,000,000	115·7407
700,000	8·1018				

CHAPTER XII.

DUTY OF WATER, AND AGRICULTURAL.

Duty of water in perennial irrigation in summer, winter and flood—Duty of water in basin irrigation and colmatage—Drainage cuts for colmatage, rice and ordinary lands—Drainage cuts in the Second Circle of irrigation—Duty of water in Upper and Lower Egypt—Engines and pumps—Sizes of pumping engines—Cost of pumping—Advertised duty of pumps—Practical discharge of small pumps and areas capable of irrigation—"Sakyas"—"Shadoofs"—"Natâlis"—Archimedean screws—Cotton—Sugar-cane—Millets—Indian corn—Wheat, beans, barley and clover—Cost of raising crops and value of yield per acre—Theoretical and actual rotations of crops—Table of weights and measures and equivalents—Sizes of beds—Quantity of seed corn per acre—Manures—Tobacco culture and taxation—Land tax settlement history—Areas of registered land and taxes—"Kharagi"—"Ushûri"—Land tax adjustment and rent valuation—Factor governing renting values of land—Nitrates in the deserts—Manures—Cotton worm—Reclamation works in the valley of the Po—Pisciculture.

THE *duty* of water varies according to the seasons and crops to be irrigated. In *summer* the first watering *on the perennially irrigated lands*, known as the "taf el Sharâki," which irrigates the ground previous to ploughing and sowing, has an average depth of 11·5 centimetres, or 480 cubic metres to the acre of 4200 square metres. All subsequent waterings have an average depth of 8⅓ centimetres, or 350 cubic metres to the acre. *In Lower Egypt* cotton needs irrigation once in twenty days and rice once in ten days. During summer there is a considerable amount of loss from the canals and watercourses owing to percolation and evaporation; and it will be found that 5 cubic metres per acre per twenty-four hours is not too great a quantity to allow for waste. A canal in summer, therefore, should discharge $\left(\frac{350}{20} + 5\right) = 22$ cubic metres per twenty-four hours per acre of cotton to be irrigated, and $\left(\frac{350}{10} + 5\right)$ $= 40$ cubic metres per twenty-four hours per acre of rice. In other words, a discharge of 1 cubic metre per second in summer will suffice in Lower Egypt for 4000 acres of cotton or 2150 acres of rice.

In the above calculation it has been assumed that cotton is irrigated once every twenty days in May and June. All agriculturists who can command the supply irrigate once every fifteen days, but one irrigation per twenty days is all that is given in nine cases out of ten, owing to the scarcity of water at the time of the year, and consequently I have adopted

that figure as a standard. Irrigated steadily in this manner, fields everywhere give magnificent yields of cotton.

In *Upper Egypt*, where the heat and evaporation are both much greater in summer, cotton and sugar-cane need from 25 to 33 per cent. more water than they do in the Delta. One cubic metre of water per second suffices therefore for 3000 acres of cotton or sugar-cane. Rice in Upper Egypt is a flood crop.

At the beginning of the *flood*, the perennially irrigated land to be put under flood irrigation needs a depth of 11·5 centimetres as a minimum, which means 480 cubic metres per acre. This quantity is given if the first "taf el Sharâki" irrigation is by lift. Where the irrigation is by free flow the acre may receive as much as 600 or even 700 cubic metres. Since one-half the area commanded is on an average being put under flood irrigation at the same time, and as the earlier the Indian corn is sown the more it yields, and consequently every cultivator is straining his utmost to irrigate his field as quickly as possible; the demand for water at the beginning of the flood is unlimited, and canals can carry any supply, the more the better. As soon as the whole area has received its first irrigation, and the flood crop is sown, the second and subsequent waterings are given every twelve days. These waterings have the same depth as in summer, viz. 8⅘ centimetres, and therefore a discharge of $\left(\frac{350}{12}\right) = 29$ cubic metres per twenty-four hours suffices for each acre of land. During flood the evaporation is the same as in summer, but the canals are full of water and very deep, and the evaporation therefore bears a very small proportion to the amount carried and may be neglected. The percolation also is inconsiderable after the first three weeks of heavy demand, owing to the Nile itself being in flood and supplying the springs, and the whole country having just been very heavily irrigated. In flood, therefore, the losses by percolation and evaporation may be neglected after the first watering. In other words, at the beginning of the flood a canal can carry any supply one chooses to send down, while during the flood a discharge of 1 cubic metre per second will suffice for 3000 acres of Indian corn and cotton. The rice lands during the flood receive flush irrigation, and have every cubic metre put on them that the drains can possibly carry away.

As before, in Upper Egypt during flood 1 cubic metre per second suffices for 3000 acres. Where flood sorghum is irrigated on the Nile berms by means of shadoofs worked by men, the fields are irrigated every ten days, but as the depth of each watering does not exceed 6 millimetres as against 8⅘ centimetres for the fifteen days' waterings, the quantity required per day remains constant.

In *winter* the average depth of water a field receives is 10 centimetres in the perennially irrigated tracts, and the fields are irrigated

once in forty days. A canal during winter should therefore discharge $\left(\frac{4200 \times 10}{100} \times \frac{1}{40}\right) = 11$ cubic metres per acre per day. In other words, a discharge of 1 cubic metre per second will suffice for 8000 acres. In the northern parts of the Delta, however, when lands under clover are washed during the winter, a considerably large discharge of water is necessary. This discharge will depend on the capacities of the drains and the escapes.

The carrying capacities of *basin canals* are given on pages 65, 73, 83, and very fully on page 92. In a mean year the existing basins of Egypt receive 125 cubic metres per acre per twenty-four hours for forty-five days, or, in other words, 1 cubic metre per second suffices for 700 acres.

For *Colmatage* or *Warping* in Lower Egypt, known locally as "Tanîl," a depth of 60 centimetres of water changed every fifteen days is the maximum which is ever given. Under such conditions an acre receives 170 cubic metres per twenty-four hours, or 1 cubic metre per second suffices for 500 acres. The discharging drain needs to have this capacity, and it is scarcely necessary to add that except in favourable and limited localities, such discharges are out of the question. As colmatage can be carried on for ninety days against the forty-five days of basin irrigation, and as 1 cubic metre per second suffices for the basin irrigation of 700 acres, we may conclude that for colmatage a discharge of 1 cubic metre per second per 1400 or 1500 acres should be ample. If we allow 25 per cent. of the area under reclamation to receive colmatage annually and the remaining $\frac{3}{4}$ to be treated like rice lands, the drainage cuts will need to be of such a capacity that they can discharge 1 cubic metre per 5000 acres in flood. This proportion is a fair and reasonable one for such land, and any drain which could ensure such drainage to the area under reclamation would meet all reasonable requirements.

For *drainage cuts* to drain the water off rice fields there can be no hard and fast rules. Provided the drain will flow, the irrigation will be made to suit it. No drain, however, which professes to drain rice lands should have a less flow than one-third the minimum irrigation needed for rice. It should therefore as a minimum have a discharge of $\left(\frac{40}{3}\right)$, or 13 cubic metres per acre per twenty-four hours. This means a discharge of 1 cubic metre per second per 6500 acres. Since the infiltrations in the ordinary clay soil of Egypt are generally between 1 and 3 (say 2) millimetres per twenty-four hours, once the whole area irrigated, no drain of any kind should discharge less than $\left(\frac{4200 \times 2}{1000}\right) = 8 \cdot 5$ cubic metres per acre per twenty-four hours, or the land will be more or less water-logged. In other words, a minimum discharge of 1 cubic metre per second per 10,000

acres should everywhere be assured. Drains should be deep rather than broad, owing to the inability of weeds to grow in deep water if it is at all muddy.

The following very interesting table has been sent me by Ismail Bey Sirry and Mr. Tottenham of the Second Circle of irrigation. It shows the areas drained and the quantities of water discharged by the drains of the Second Circle of irrigation. For drains Nos. 1, 4, 5 and 6 the discharges and area measurements have been made at some point on the drain and again at the tail. It will be noticed that some of the drains like Nos. 1 and 11 discharge more than the theoretical minimum, but generally the drains discharge less than the theoretical minimum. In the theoretical discharge columns it has been assumed that half the reclaimed land is fit for dry crops and half for rice and wet crops, and that consequently 1 cubic metre per second of discharge will suffice for $\left(\frac{6500 + 10{,}000}{2}\right) = 8000$ acres. For the waste land and land under reclamation it has been assumed that one-fourth will be put under colmatage every year and the other three-quarters be treated like rice land. In such land 1 cubic metre per second of discharge will suffice for 5000 acres.

Recapitulating what has been already stated, we may note that

In Lower Egypt, in summer—

1 *cubic metre of water per second* suffices for the irrigation of 4000 acres of cotton and Indian corn, or for 2150 acres of rice; or

1 *cubic metre per minute* suffices for 66 acres of cotton or for 36 acres of rice.

Cubic metres per second may be conveniently used for canals, and cubic metres per minute for pumping engines.

In Upper Egypt, in summer—

1 *cubic metre per second* suffices for 3000 acres of cotton or sugar-cane; or

1 *cubic metre per minute* suffices for 50 acres of cotton or sugar-cane.

The above figures have reference to canals and watercourses perpetually flowing. If the canals have rotations, or the pumping engines run eighteen or twenty hours out of the twenty-four, the duty must be proportionately diminished.

During flood the irrigation is practically "flush" everywhere; during winter it is "flush" in many localities by rotation, while during summer it should be generally "lift." To prevent excessive infiltrations, in all but rice lands, it is better to keep the water surface low, and lift the water during summer. *The water is lifted* on to the fields by any of the following methods:—

1. *Engines and pumps;*
2. *Sakyas, taboots, screws*, &c., worked by oxen;
3. *Shadoofs*, worked by men;
4. *Natâlis*, worked by men.

DRAINS IN THE SECOND CIRCLE OF IRRIGATION, 1898.

No. of Drain	Area on Drainage Cut in acres			Length of Drains in kilometres	Bed Width in metres	Depth of Water in metres	Slope of Bed	Discharge, cubic metres per second	Theoretical Discharge Needed		
	Area Reclaimed	Under Reclamation and Waste	Total						Reclaimed area at 1 cubic metre per second per 8000 acres	Under reclamation at 1 cubic metre per second per 5000 acres	Total
No. 1	39,250	45,250	84,500	35	8	2·0	$\frac{1}{12500}$	9	5	9	14
" 1	64,800	47,000	111,800	79	22	2·0	$\frac{1}{16666}$	24	8	10	18
" 2	29,200	36,800	66,000	38	8	2·0	$\frac{1}{16666}$	8	4	7	11
" 3	14,200	35,800	50,000	25	5	1·8	$\frac{1}{20000}$	3	2	7	9
" 4	36,100	53,700	89,800	28	8	2·0	$\frac{1}{16666}$	9	5	11	16
" 4	59,100	88,900	148,000	53	10	2·0	$\frac{1}{14285}$	11	10	18	28
" 5	25,000	27,500	52,500	30	6	1·5	$\frac{1}{16666}$	4	3	6	9
" 5	40,000	39,000	79,000	45	8	2·0	$\frac{1}{14286}$	9	5	8	13
" 6	60,000	4,500	64,500	40	6	2·0	$\frac{1}{14286}$	7	8	1	9
" 6	110,000	20,000	130,000	55	13	2·0	$\frac{1}{14286}$	15	14	4	18
" 7	60,000	20,000	80,000	50	8	2·0	$\frac{1}{16666}$	8	8	4	12
" 8	40,000	20,000	60,000	45	8	2·0	$\frac{1}{16666}$	8	5	4	9
" 9	15,000	15,000	30,000	25	6	1·5	$\frac{1}{20000}$	4	2	3	5
" 10	15,000	10,000	25,000	17	7	1·5	$\frac{1}{20000}$	4	2	2	4
" 11	20,000	20,000	40,000	20	9	2·0	$\frac{1}{14286}$	10	3	4	7
Total	467,300	352,500	819,800	..	..	..	..	104	63	71	134

Engines and pumps.—1. As a rule, *portable engines and centrifugal pumps* are used, owing to their great convenience and power to resist wear and tear. The 8-H.P. engine and the 8-in. pump are the machines most commonly used. The engine is placed on a plot of level ground, and the pump supported on a wooden trestle, or fixed inside a cheap masonry well. Where capital is available and the estate a large one, a stationary engine and pump are of course preferred. Where the lift is above 3 metres, centrifugal pumps are almost always preferred; where the lift is under 3 metres, water-wheels of different kinds are also employed. The fuel used is ordinarily coal, though occasionally one sees cotton and bean stalks. In Upper Egypt, where coal is dear, wheat straw and Indian corn stalk are often used. The engines are generally worked for 12 hours per day.

2. "*Sakyas*" (*or Persian wheels*) are used where the lift is over 3·5 metres, and "*taboots*" (or wheels delivering water at the periphery) when the lift is under 3 metres. They are driven by a single animal, or a pair: cows and female buffaloes are generally employed. It is not an uncommon sight to see the wheel replaced by an Archimedean screw driven by oxen when the lift is about 1 metre or 1½ metre. They lift the water to the required height, and not from 1 metre to 1½ metre higher than necessary, as is done by the taboots and sakyas.

3. "*Shadoofs*," or poles with bucket and counterpoise, are used where the irrigation is temporary, or where the men cannot afford a "Sakya." Where the lift is only 1 metre they are often replaced by *Archimedean screws* worked by hand.

4. "*Natâlis*" (Indian bôkas), or buckets worked by strings, are used where the lift is under 1 metre, and where, owing to the fluctuating supply, flush irrigation is frequent.

The *sizes of pumps* recommended *practically* for different sized engines and different lifts are detailed below:—

Portable Engine	4 H.P.	6 H.P.	8 H.P.	10 H.P.	12 H.P.	14 H.P.	16 H P.	20 H.P.	25 H.P.
	inches	inches	inches	inches	inches	inches	inches	inches	inches
1 mètre lift .	6	8	10	14	16	18	20	24	30
2 metres lift .	5	8	10	12	15	16	18	22	30
3 „ .	5	8	10	12	15	16	18	22	30
4 .	4	6	8	10	12	14	16	20	24
5 „ .	4	6	8	10	12	14	16	20	24

The ordinary rule is to make the pump the same number of inches as the engine has H.P., but this means waste of power in low lifts.

The cost of working a 10-H.P. engine in the interior may be estimated as follows :—

1. Driver and stoker, per day	£·15	
2. Oil, &c., per day	·05	
3. Coal per day (away from navigable canals) .	1·00	Maximum price of 1000 lbs.
4. $\frac{1}{365}$ of 10 per cent. per annum on cost of engine for depreciation, repairs, &c.	·10	
Total	£1·30	

Mr. Mabardi, of Messrs. Steinman & Mabardi, of Alexandria, has kindly given me the following table giving practical cost of working ordinary pumping engines in the interior of Egypt.

—	Portable					Fixed			
	6-inch	8-inch	10-inch	12-inch	14-inch	15-inch	16-inch	18-inch	20-inch
Cost of working per hour, in piastres .	7	9	12	15	17	16	17	18	19

According to the above table a 10-in. pump with presumably a 10-H.P. engine would cost for 12 hours, 12 × 12 = 144 piastres or 1·44*l.*, as against 1·30*l.* of the previous estimate.

The number of acres of cotton irrigated in 12 hours by a 10-H.P. engine would be 15 ; therefore the cost of irrigating an acre once would be ·10*l.* Since cotton receives a watering every twenty days between March and August, the number of waterings would be 7½ ; and consequently the cost of irrigating an acre of cotton through the summer would be ·75*l.* The above applies to all localities in Lower Egypt where the lift is under 4 metres, above that the cost is slightly increased.

Pump owners used to charge the fellaheen from ·25*l.* to ·45*l.* per acre per watering, and made a very handsome profit out of the business. The ordinary price now is ·20*l.* per acre per watering.

Ordinarily an 8-H.P. engine and 8-in. pump, with a 4-metre lift, irrigate in twelve hours eleven acres of cotton, sugar or rice. A 10-H.P. engine and 10-in. pump irrigate in twelve hours fifteen acres. In the twelve hours the engine runs about eleven hours. Since rice needs water more frequently than cotton, a rice engine works much more steadily than a cotton one. An 8-H.P. engine and 8-in. pump are considered by the fellaheen capable of

irrigating 120 acres of cotton or 100 acres of rice; while a 10-H.P. engine and 10-in. pump are considered capable of irrigating 180 acres of cotton or 140 acres of rice.

The following table gives the advertised working powers of engines and pumps :—

ADVERTISED DUTY OF PUMPS.

Diameter of Pumps in inches	Discharge in gallons per minute	Discharge in cubic metres per minute	Nominal H.P. of Engine required			
			3 metres Lift	4 metres Lift	5 metres Lift	6 metres Lift
3	100	·45	1·0	1·5	2	2
4	200	·9	1·5	2·5	3	3
5	350	1·6	2·0	3	4	4
6	500	2·3	2·5	4	5	5
7	750	3·4	3·0	4	5	6
8	1000	4·5	4·0	6	7	8
10	1500	6·8	6·0	8	9	10
12	2300	10·4	8·0	10	12	14
14	2800	12·7	10·0	12	14	16
15	3400	15·4	12·0	15	18	20
18	6000	27·2	20·0	25	30	35

Mr. Lang Anderson, of Abukîr, has supplied me with the following practical rule for calculating the discharge of centrifugal pumps.

Square the diameter in feet and multiply by 10, and the result will be the discharge in cubic metres per minute.

			Cubic metres per minute
6-inch pump . . .	·5 × ·5 × 10	=	2·5
12-inch "	1 × 1 × 10	=	10·0

These results compare very favourably with the figures in the preceding table.

As a result of sixty very carefully made observations in the Delta, I found that with the *ordinary portable engines and pumps in use in the country the discharge was $\frac{2}{3}$ cubic metre per H.P. per minute.* By H.P. is here meant the nominal H.P. of commerce. In other words :—

A 6 H.P.	engine and pump	would deliver		4·0	cubic metres	per minute.
8	"	"	"	5·3	"	"
10	"	"	"	6·6	"	"
12	"	"	"	8·0	"	"

As 1 cubic metre per minute suffices for 66 acres of cotton and Indian corn in the Delta, taking rotations into consideration,

A 6 H.P.	engine and pump	would	irrigate	130	acres of cotton	and Indian	corn.
8	"	"	"	175	"	"	"
10	"	"	"	220	"	"	"
12	"	"	"	260	"	"	"

And if we assume that half the area will be under cotton, as it ordinarily will,

A 6 H.P.	engine and	pump will	serve	260	acres of cotton-	and corn-producing	land
8	"	"	"	350	"	"	"
10	"	"	"	440	"	"	"
12	"	"	"	520	"	"	"

The above figures apply to engines and pumps put up on canals where the lifts are always under 4 metres. It should be noticed that the H.P. is the nominal horse-power of commerce.

For the large stationary engines erected on the Nile in Upper Egypt, of which details are given in Chapter VII., the calculations have thus been made:—

Extreme lift in summer = 9 metres.

Effective H.P. of water delivered = $\frac{1}{2}$ indicated H.P. of engine.

1 H.P. = 75 kilogrammetres per second.

1 cubic metre of water = 1000 kilogrammes.

Water delivered per indicated H.P. per *minute* $= \frac{1}{2} \times \frac{75}{1000} \times \frac{60}{9} = \frac{1}{4}$ cubic metre per minute.

In Upper Egypt 1 cubic metre per minute will ensure the irrigation of 50 acres of sugar-cane or cotton, and assuming in extreme summer that the pump will work $\frac{4}{5}$ of twenty-four hours per day.

One indicated H.P. will ensure the irrigation of $\frac{4}{5} \times \frac{1}{4} \times 50 = 10$ acres.

The cost of irrigating this area will be as follows :—

The coal consumed will be $1\frac{1}{4}$ kilogramme per H.P. per hour, and as the engine will work $\frac{4}{5}$ of twenty-four hours, the consumption per H.P per day will be $\frac{4}{5} \times 24 \times \frac{5}{4} = 24$ kilogrammes.

Cost of coal per day $= 24 \times \cdot 18$ piastres	$=$	$4 \cdot 32$ piastres
„ engine driver, &c.	$=$	$\cdot 68$ „
Total		$5 \cdot 00$ piastres

Per H.P. per day.

The cotton and sugar-cane will be irrigated once in fifteen days. The cost per H.P. per fifteen days will be $15 \times 5 = 75$ piastres.

The area irrigated being 10 acres, each acre will cost $7 \cdot 5$ piastres per watering. No count has been taken of interest charges on the cost of installation, or of depreciation or of repairs.

The amount of water lifted in fifteen days will be $15 \times \frac{4}{5} \times \frac{1}{4} \times 60 \times 24 = 4320$ cubic metres. Of the 4320 cubic metres, each acre of ·10 will nominally receive 432 cubic metres, but about 380 will actually reach the fields and the balance be wasted in the watercourses.

Towards the end of Mr. Verschoyle's note in Appendix IV. it is stated that the cost of raising water at Mex with powerful centrifugal pumps to a height of from 2 to 3 metres is 27*l.* per million cubic metres. This is probably as cheap as it is possible to do such work in Egypt.

"*Sakyas*" are used for high lifts and "*Taboots*" for low lifts. They have the duty detailed below :—

Lift in metres	Discharge in cubic metres per minute through the 12 hours	Acres of Cotton irrigated in 12 hours	Acres generally put under Cotton on a Sakya or Taboot			Remarks
			With 1 Ox	With 2 Oxen	With 3 Oxen	
1 to 2	·40	·80	8	14	20	The acreage does not alter much, but there is a great difference in the extent to which the cattle are fatigued.
2 to 4	·25	·50	4	8	12	
4 to 6	·20	·45	4	7	11	
6 to 8	·15	·33	3	6	10	

If the oxen are hired, the charge per pair of oxen per twelve hours will be ·20*l.*, but almost invariably home stock is used.

A "*Shadoof*" worked by one man gives the following duty :—

Lift in metres	Discharge, cubic metres per minute	Acres of Cotton or Corn Irrigated in 12 hours	Acres generally put under Cotton or Corn	Remarks
0–2½	·050	·10	1	When the lift exceeds 2½ metres, two shadoofs are used; when the lift exceeds 4½ metres, three shadoofs are used.

If labour is taken at 3 piastres per day of twelve hours in Lower Egypt and 1½ piastres per day of twelve hours in Upper Egypt, the cost of irrigation can be worked out. Generally the man works for his own crop. Two men working at one "Shadoof" in alternate spells of one hour, will do 50 per cent. more work than the above.

With a *Natâli*, four men working in relays of two men can irrigate 1 acre in twelve hours with a ·25 ¼-metre lift, ¾ of an acre with a ½-metre lift, and ½ an acre with a ¾-metre lift.

With an *Archimedean Screw* two men do the same work that four can do with a Natâli.

IN UPPER EGYPT

Cotton sowing begins on the 20th February and terminates on the 5th April. The cotton harvest begins on the 5th August and terminates on the 15th October. The land receives the taf el Sharâki watering before ploughing, and then a watering when the seed is sown. About twenty days subsequently it receives a second watering, a third watering after another thirty or forty days, and then a watering every fifteen days. Up to the end of July the land receives nine waterings. This means some 3600 cubic metres per acre. In August and September the crop receives four waterings, and one watering in October with the red water of the flood, or some 2000 cubic metres per acre. The land is then very heavily irrigated and the winter crop is sown, which receives some two waterings or another 1500 cubic metres per acre. Allowing 5 cubic metres per acre per day lost in the canals and watercourses during the summer, we have an additional 900 cubic metres per acre per annum. Such land therefore receives in the twelve months some 8000 cubic metres per acre, or a vertical depth of 1·90 metre.

Sugar-Cane sowing begins in the last week of February and terminates on the 5th April. The harvest begins on the 15th December and terminates on the 15th March. It is irrigated steadily every twelve or fifteen days through summer and flood up to the 15th of November, and after that if there is any frost in the winter. During summer it receives ten waterings.

From Sir R. Hamilton Lang's report on the Daira Sania Administration for 1896, I have obtained the information shown in table on page 377. A cantar or kantar of canes is almost the same as a cwt., and about 22½ kantars make a ton. A ton of sugar-canes yields to all practical purposes a tenth of a ton of sugar.

Gedi or *Summer Sorghum* in the basins is begun to be sown on the 20th March. Sowing terminates on the 20th April. The harvest begins on the 1st August and terminates on the 15th August. This crop is watered from wells in the fields by "Shadoofs" and by "Sakyas," and is irrigated every ten days until it is harvested. It receives on an average a depth of water of some 3000 cubic metres per acre.

Nabari or *Flood Sorghum* is sown either on the Nile berms or in the basins. Sowing begins on the 5th August and terminates on the 5th September. The harvest begins on the 5th December and terminates on the 25th December. This crop is watered by "Shadoofs" and "Sakyas" working on the Nile or on the canals, and is irrigated every ten or fifteen days till the 15th November. The amount of water put on the acre is about 2250 cubic metres.

Winter Crops, such as wheat, beans, clover and barley. Sowing begins on the 5th October and terminates on the 30th November. The barley and bean harvest begins on the 10th March and terminates on the 10th April. The wheat harvest is about a month later. In the basins such lands are not watered as a rule. In Esna and Kena, where the hills produce nitrates, the cereals are manured and irrigated two or three times, from wells in the fields and from the Nile.

Lower Egypt.

Cotton sowing begins on the 20th February and terminates on the 5th April. The harvest begins on the 20th August and terminates on the 10th November. The cotton is picked twice or three times. This crop generally follows clover. The land receives one watering before ploughing and another when the seed is sown. The next watering is given after twenty days, and then there is a break of forty days. Subsequently the cotton is irrigated every fifteen or twenty days. Before the flood the land receives from seven to eight waterings, or some 3000 cubic metres per acre. In flood and winter the same rules apply to the irrigation as in Upper Egypt. Land in Lower Egypt under cotton in summer and under winter crops in winter receives about 7500 cubic metres of water per acre, or a vertical height of 1·80 metre. When drains exist and the clover is washed and drained, of course a larger quantity of water is used.

Indian Corn or *Durra*) Amerikâni and Baladi). Sowing begins on the 5th July and terminates on the 30th August. The harvest begins on the 15th October and terminates on the 30th November.

"The following table shows the total quantity of sugar-canes delivered to the Factories in 1896, and the yield per acre :—

Factory	Canes from Daira Cultures			Canes from Daira Tenants			Canes from Private Individuals.		
	Acreage	Cantars	Average per acre	Acreage	Cantars	Average per acre	Acreage	Cantars	Average per acre
Erment . .	387	148,852	384	1,714	777,458	454	176	77,541	441
Motana . .	207	92,446	446	1,452	770,358	531	82	41,590	507
Dabbeiyah .	101	43,302	431	1,493	864,738	579	162	87,529	540
Rodah . .	214	121,795	570	2,851	1,200,894	422	1,762	835,064	474
Abukurgas .	456	168,684	370	1,925	919,596	475	1,688	854,490	506
Minieh . .	575	177,665	309	3,379	1,588,260	470	2,533	1,160,715	458
Mattai . .	1	125	334	2,145	979,572	457	2,705	1,232,339	456
Magagha .	389	180,220	463	4,636	1,984,822	429	2,556	992,164	388
Bibeh . .	521	172,397	330	4,305	1,644,731	382	2,329	1,010,516	434
	2,851	1,105,486	388	23,900	10,723,429	449	13,993	6,291,948	450
In 1895 .	1,786	736,049	412	25,974	11,032,560	425	11,262	5,615,799	498
In 1894 .	2,323	1,079,903	464	26,664	10,964,479	411	10,000	4,458,129	445

Grand total, 1896, acres, 40,744; cantars, 18,120,864; average, 445.
" 1895, " 39,024; " 17,384,409; " 445.
" 1894, " 38,970; " 16,502,512; " 425.
" 1893, " 37,134; " 14,693,083; " 396.
" 1892, " 34,698; " 14,517,587; " 418."

The American variety is irrigated when it is sown, then twenty days after, and subsequently every ten or twelve days till it is reaped. The Egyptian variety is watered at sowing, fifteen days after sowing, and then every twelve or fifteen days till it is reaped.

Sultâni Rice is sown from the 5th May to the 5th June. The harvest is reaped during November. This crop needs as a minimum 40 cubic metres per acre per day, and in flood receives as much as the drains can possibly carry away.

Sabaini Rice is sown as soon as the flood arrives, about the 5th August, and is sown up to the 5th September. It is reaped at the same time as the Sultâni, and receives as much water as the drains can dispose of.

Winter Crops, wheat, beans, barley and clover. Sowing begins on the 25th October and terminates for wheat on the 10th December, beans on the 20th, and barley on the 30th.

The bean and barley harvest lasts from the 15th April to the 5th May, while the wheat harvest is some twenty days later. Clover is irrigated later, till the 1st June.

The wheat is irrigated about thirty-five days after sowing, and then once again. Beans are irrigated twenty days after sowing, and then once again. Barley is irrigated once about forty days after sowing.

The tables on pages 379 to 382 have been prepared for me by experienced agriculturists. The quality of land varies so considerably that it is difficult to get the same opinion from two men, but these tables represent the opinions of eminently successful men, who manage their own estates.

The *Theoretical Rotations* of crops in the rich lands in Lower Egypt are as follows :—

	Winter	Summer and Flood
1st year	Clover or fallow	Cotton.
2nd year	Wheat or clover	Indian corn.
3rd year	Beans or clover	Indian corn.

In the poor lands they are as follows :—

	Winter	Summer and Flood
1st year	Clover	Cotton.
2nd year	Clover or barley	Rice.
3rd year	Barley	Fallow.

The *Actual Rotations* of crops are as follows :—

In the rich lands—

	Winter	Summer and Flood
1st year	Clover	Cotton.
2nd year	Beans or wheat	Indian corn.
	and so on.	

In the poor lands—

	Winter	Summer and Flood
1st year	Clover	Cotton.
2nd year	Clover	Cotton.
3rd year	Barley	Rice or fallow.

TABLE I.—COST OF RAISING CROPS, AND YIELD PER ACRE OF GOOD LAND IN UPPER EGYPT.

Name of Crop	Cost of Raising							Value of Yield					Net Profit	Remarks
	Ploughing and Sowing	Seed	Irrigation	Weeding and Reaping	Manure	Carriage to Market	Total	Yield of Grain and Seed		Yield of Straw or Fibre		Total		
								Quantity	Value	Quantity	Value			
	£	£	£	£	£	£	£	ardebs	£	cantars	£	£	£	
Sugar-cane	1·50	2·50	2·0	3·5	·5	..	10·0	..	..	600	24·0	24·0	14·0	Yielding 6 tons of sugar. Summer irrigation.
Cotton . .	1·2	·15	·5	1·5	..	·2	3·55	..	..	7*	15·0	15·0	11·45	Summer irrigation.
Wheat . .	·4	·5	·2	·5	..	..	1·6	6	4·0	8	1·2	5·2	3·6	Ibrahimia tracts.
Indian corn	·20	·15	·50	·30	..	..	1·15	10	6·00	..	·50	6·50	5·35	High lands near Nile.
Millets .	·20	·15	·50	·30	..	..	1·15	10	5·00	10	·50	6·50	5·35	For "cantars" and "ardebs," see page 383.
Vegetables	..	..	..	..	..	..	..	..	..	..	..	..	10·00	
Wheat . .	·05	·5	..	·5	..	..	1·05	7	5·25	10	1·50	6·75	5·70	Basins.
Beans . .	·05	·45	..	·4	..	..	·90	7	4·90	8	1·00	5·90	5·00	Basins.
Clover . .	·05	·15	..	..	..	..	·20	..	..	..	..	5·00	4·80	Basins.

* Mitaffi cotton.

TABLE II.—COST OF RAISING CROPS, AND YIELD PER ACRE IN THE GOOD LANDS IN THE SOUTHERN HALF OF LOWER EGYPT.

Name of Crop	Cost of Raising. Ploughing and Sowing	Seed	Irrigation	Weeding and Reaping	Manure	Carriage to Market	Total	Value of Yield. Yield of Grain and Seed: Quantity	Value	Yield of Straw or Fibre: Quantity	Value	Total	Total Profit	Remarks
	£	£	£	£	£	£	£	ardebs	£	cantars	£	£	£	
Cotton . .	1·20	·15	2·10	1·50	1·00	·20	6·15	..	..	6·50*	13·5	13·5	7·35	Half the cost of manure is debited to cotton and half to Indian corn.
Sugar-cane	1·20	2·00	3·00	1·50	1·50	..	9·20	sold in	field	..	..	40·0	30·80	For eating.
Fruit . .	..	..	5·00	..	5·00	..	10·00	..	..	..	..	40·0	30·00	
Vegetables	..	..	..	..	..	..	3·00	..	..	..	..	15·0	12·00	
Kulkas .	3·00	5·00	6·00	4·00	2·00	2·00	22·0	..	..	..	..	48·0	26·00	Articles de luxe.
Indian corn	·40	·20	..	1·00	1·0	..	2·6	10	6·0	seeds	..	6·0	3·4	
Wheat . .	·40	·50	·50	1·00	..	..	2·4	6	5·0	10	2·0	7·0	4·6	
Beans . .	·40	·50	·50	1·00	..	..	2·4	6	5·0	..	1·0	6·0	3·6	
Barley . .	·40	·25	..	1·00	..	..	1·6	8	3·0	..	1·5	4·5	2·9	
Clover . .	..	·50	2·0	..	..	..	2·5	..	..	..	..	7·5	5·0	Irrigated.
Clover . .	..	·50	..	..	..	..	·5	..	..	..	..	4·4	4·0	Unirrigated.
Onions . .														

* Mitafifi cotton.

TABLE III.—COST OF RAISING CROPS, AND YIELD PER ACRE OF SUPERIOR LAND IN NORTHERN HALF OF UPPER EGYPT.

Name of Crop	Cost of Raising: Ploughing and Sowing	Cost of Raising: Seed	Cost of Raising: Irrigation	Cost of Raising: Weeding and Reaping	Cost of Raising: Manure	Cost of Raising: Carriage to Market	Cost of Raising: Total	Value of Yield. Yield of Grain and Seed: Quantity	Value of Yield. Yield of Grain and Seed: Value	Value of Yield. Yield of Straw or Fibre: Quantity	Value of Yield. Yield of Straw or Fibre: Value	Value of Yield. Total	Net Profit per Acre	Remarks
	£	£	£	£	£	£	£	ardebs	£	cantars	£	£	£	
Cotton . .	1·1	·3	1·0	1·2	·7	·4	4·7	..	..	5*	10	10·0	5·30	
Sultani rice .	..	..	..	..	..	..	..	..	..	..	7	7·0	3·50	
Flood rice .	..	..	..	..	..	..	..	..	..	..	2	2·0	1·00	Half the cost of manure is debited to cotton and half to Indian corn. The Indian corn gets nearly the whole benefit.
Indian corn .	·45	·15	..	·45	1·0	..	2·05	7	4·9	..	..	4·9	2·85	
Vegetables .	..	..	..	..	..	..	1·0	..	..	..	..	4·0	3·00	
Wheat. . .	·4	·5	·2	1·0	·5	..	2·6	5	5·0	..	1·0	6·0	3·40	
Barley . .	·4	·3	·2	1·0	·5	..	2·4	8	4·0	..	1·0	5·0	2·60	
Clover . .	..	·5	1·0	..	..	..	1·5	..	..	..	..	5·0	3·50	

* Mitafifi cotton.

TABLE IV.—COST OF RAISING CROPS, AND YIELD PER ACRE OF INFERIOR LAND IN NORTHERN HALF OF LOWER EGYPT.

Name of Crop	Cost of Raising							Value of Yield					Net Profit per Acre	Remarks
	Ploughing and Sowing	Seed	Irrigation	Weeding and Reaping	Manure	Carriage to Market	Total	Yield of Grain and Seed		Yield of Straw or Fibre		Total		
								Quantity	Value	Quantity	Value			
	£	£	£	£	£	£	£	£	£	cantars	£	£	£	
Cotton . .	·5	·3	1·0	·8	..	·2	2·8	..	..	3*	5·0	5·0	2·2	No manure.
Sultani rice .	..	..	..	..	..	..	..	..	..	..	..	5·0	2·5	Yield of cotton is in "cantars" of 100 lbs. each. Yield of cereals in "ardebs," each ardeb = 5 bushels nearly.
Flood rice .	..	..	..	..	..	..	..	..	..	..	..	2·0	1·0	
										ardebs				
Indian corn .	·4	·15	..	·4	..	..	·95	..	..	3	2·4	2·4	1·45	
Wheat . .	·3	·5	..	·4	..	..	1·2	..	·75	2·5	2·5	3·25	2·05	
Barley . .	·4	·3	..	·3	..	..	1·0	..	·75	4·0	2·0	2·75	1·75	
Clover . .	..	·5	..	..	..	..	·5	..	..	..	..	3·0	2·50	

* Mitafifi cotton.

The following table explains all *local weights and measures* used in this book :—

WEIGHTS AND MEASURES.

Comparison between French and English.

1 metre	=	3·28090 feet	..	1 foot	=	·304794 metre.
1 sq. metre.	=	10·7643 sq. feet	..	1 sq. foot	=	·09290 sq. metre.
1 cub. metre	=	35·3166 cub. feet	..	1 cub. foot	=	·028315 cub. metre.
,, ,,	=	220·097 gallons	..	1 gallon	=	·004543 ,,
,, ,,	=	27·5121 bushels	..	1 bushel	=	·036348 ,,

1 kilogramme	=	2·2046 lbs.
1 lb.	=	·453593 kilogramme.
1 French H.P.	=	·986337 English H.P.
1 English H.P.	=	1·01385 French H.P.
1 acre	=	4046·71 square metres.
5 miles	=	8 kilometres (approximatively).

Egyptian.

Length.—	1 pic (architects')	=	·75 metre.
	1 Pic (Nile gauge	=	·54 ,,
	1 Kassaba	=	3·550 metres.
Square.—	1 Feddan (acre)	=	4200·833333 square metres.
	1 Kirat square	=	175·034722 ,,
	1 Kassaba	=	12·602500 ,,
Cube.—	1 Kassaba cube	=	44·738875 cubic metres.
Dry measure.—	1 Ardeb	=	·19774770 cubic metres = 5·4404 bushels.
	1 Kelah	=	$\frac{1}{12}$ ardab = ·016478975 cubic metres.
Weight.—	1 Ratl	=	·4449312 kilogramme = ·9809 lb.
	1 Ocque	=	1·235920 ,, = 2·7245 ,,
	1 Kantar	=	44·49312 ,, = 98·09 ,,
Money.—	£1 Egyptian	=	100 piastres = 1000 millimes.
	£1 English	=	97½ ,, = 975 ,,

Liquids are weighed in Egypt.

The English acre, pound, and £ are very nearly the same as the Egyptian acre (feddan), the Egyptian pound (ratl), and the Egyptian £ (known in the country as the guinea).

In this book the Egyptian acre and the Egyptian £ have been invariably employed.

1 Kantar of cotton in seed weighs about 315 ratls, of which the cotton weighs about 100 ratls, and the remaining 215 ratls make about ⅔ of an ardeb of cotton seed.

1 Kantar of ginned cotton weighs 100 ratls = 98·09 lb.
1000 ardebs of cotton seed = 118 tons.
100 „ of wheat = 63 quarters.
100 „ of beans = 66 „
1 Dariba of rice before husking = 18 kantars.

The produce of the fields is always spoken of in ardebs (1 ardeb = 5·44 bushels), while seed corn is always spoken of in kêlas (1 ardeb = 12 kêlas).

Wheat, straw, cotton stalk, &c., are always given in himmals or camel loads of between 500 and 600 lbs.

For lift irrigation from Persian wheels or "sakyas," the *sizes of beds* vary from 10 metres × 2 metres to 10 metres × 5 metres; for irrigation from pumps the sizes of beds vary from 10 metres × 10 metres to 20 metres × 15 metres. With flush irrigation the beds vary from the small sizes used for lift irrigation to the whole field.

The *quantity of seed sown per acre* is as follows:—

Wheat, after cotton	8 kêlas.
„ Indian corn	7 „
„ fallow or flood	6 „
Barley, if ploughed	6 „
„ after fallow or flood	5 „
Indian corn	3 „
Sultani rice	2 „
Sabaini „	4 or 5 kêlas.
Sugar-cane	50 to 100 kantars.
Clover	2 kêlas.
Beans, if ploughed	8 „
„ (in basins)	6 „
Cotton	2½ „

The ordinary *manure* of Lower Egypt is the urine of farm cattle, with the ammonia fixed by dry earth, which is spread under the cattle and removed daily, and collected in heaps outside the farms. The dry atmosphere and the dry earth of Egypt combine to fix all the valuable ingredients of the urine. Before the flood, the manure is carried to the fields which are going to be planted with Indian corn, and in this way every field receives manure once every two years. For special crops, as melons, gardens, &c., pigeon guano is used.

It will have been noticed that *theoretical rotations* of crops have been spoken of. The last few years have seen the greatest changes in this respect on all except a few estates. The cotton crop of the whole of Lower Egypt, far from covering one-third the area as it is theoretically supposed to do, covers one-third only in the high lands near the apex of the Delta, further north it covers one-half the area; while north of that again it covers from two-thirds to three-fourths the area over very extensive tracts. Indeed it may

be stated that in Lower Egypt as a whole the summer crops cover half the cultivated area. In Upper Egypt also in the Ibrahîmia Canal tracts the summer crops of sugar-cane, cotton and summer sorghum cover fully half the area. In the Fayûm, of course, the proportion is considerably less. How long the land will support these exhaustive crops without any increase in the manure applied to the land it is difficult to tell, but many think that while cotton in summer is followed by clover in winter, and cereals in winter are rigidly excluded, the rotation of cotton and clover can be carried on unlimitedly without any appreciable deterioration of the soil.

It will have been noticed that no mention has been made anywhere of *tobacco.* Up to 1887 a light tax per acre was put on native-grown tobacco. It was raised in 1888, while in 1889 it stood at 50*l.* per acre. The tobacco growers immediately imported skilled labourers from Macedonia, and so improved the quality of the tobacco they grew and cured that, though the tax was raised to 100*l.* per acre in 1890, there was a considerable area put under tobacco. In 1861, tobacco growing was absolutely prohibited, and the people planted onions on the rich lands where they had previously grown tobacco. The tobacco revenue in 1897 was three times as great as it was in 1887, and as the Egyptians are inveterate tobacco smokers they must have spent nearly 700,000*l.* more on tobacco in 1897 than in 1887. The high price of tobacco is a very distinct hardship to the poor of this country, and in estimating the great advantages conferred on the country by the British occupation this fact must always be remembered as counting on the

Tobacco Revenue for Egypt from 1887 to 1897.

Year	Revenue from Native Tobacco	Octroi on Native Tobacco	Revenue on Imported Tobacco	Total Revenue from all Sources	Remarks
1887	38,874	5411	289,050	333,335	
1888	10,040	..	332,516	342,556	Octroi on native tobacco abolished in 1888.
1889	90,575	..	441,443	532,018	
1890	37,994	..	1,237,787	1,275,781	Native tobacco was prohibited in June 1890. The reason the total revenue for this year was so high is that the merchants were allowed to clear all the tobacco they had in bond before the end of the year, as the duty was raised at the beginning of 1891.
1891	..	..	318,756	318,756	
1892	..	..	655,297	655,297	
1893	..	..	788,660	788,660	
1894	..	..	932,749	932,749	
1895	..	..	968,575	968,575	
1896	..	..	1,006,525	1,006,525	
1897	..	..	1,044,780	1,044,780	

opposite side. The absolute prohibition of so valuable and suitable a crop can never be considered as anything but a makeshift while there are sound financiers in the country.

The preceding table gives the tobacco revenue from 1887 to 1897. Since 1890 Turkish tobacco pays 20 piastres per kilogramme and cut tobacco pays 25 piastres.

The standard work on *Land tenure* in Egypt is "La propriété foncière en Egypte," by Yakoub Antin Pasha, published by the Egyptian Institute in 1883.

The first settlement of the land tax in modern times was made by Mahomet Ali, in 1813, on the completion of the Cadastral survey, which measured up all cultivated land. All lands included within the Cadastre, with some notable exceptions, were called "Kharagi," and made subject to taxation. From among the lands left outside the Cadastre, numerous estates were given gratis and exempt from tax by Mahomet Ali and some of his successors to their families or to their immediate followers. These estates were called "Ushuri." The majority of them needed works of amelioration, which the corvée performed in great part. In Said Pasha's time the four provinces of Garbia, Menufia, Fayûm and Beni-Suef were all measured, and the excess found in every Hod, or subdivision of a village, was changed from "Kharagi" to "Ushuri," and handed over to the courtiers and friends of the Viceroy. Later on, in Ismail Pasha's time, the whole of Egypt was apparently thus treated.

At the first settlement of the Kharagi land in 1813 the maximum tax was 50 piastres * per acre in Upper Egypt and 45 piastres per acre in Lower Egypt.

In 1820 there was a second settlement, and in 1839 an increase of 5 per cent. on this settlement was effected.

In 1844 the Kharagi taxes were increased by one-eighth to cover the cost of collection.

Previous to 1854 the Ushuri lands had been exempt from taxation, but in that year Said Pasha subjected them to an impost of one-tenth of their gross yield, on the plea that they should pay their share of the cost of irrigation. This tax might have been paid in kind. The maximum tax for Lower Egypt was 26 piastres per acre and for upper Egypt 20 piastres per acre.

In 1857 the Kharagi taxes were increased generally by 5 piastres per acre. The maximum tax had now risen to 100 piastres per acre.

In 1864, was made the second great settlement of the land tax, and as far as can be ascertained from employés who were engaged in these operations no inspection of fields or hods was carried out at all, but the information collected from village Sheiks and other proprietors summoned

* 100 piastres = 1*l.*

to the varions governors, &c., for that purpose, formed the chief base on which the tax was fixed. After this settlement the maximum Kharagi taxes were raised to 115 piastres per acre in Lower Egypt and 110 piastres per acre in Upper Egypt, while the maximum Ushuri taxes were 35 piastres per acre in Lower Egypt and 31 piastres in Upper Egypt.

In 1867 the Ushuri land taxes were raised to a maximum of 65 piastres in Lower Egypt and 45 piastres in Upper Egypt.

In 1868 the Kharagi and Ushuri taxes were increased by a sixth as a temporary measure for four years.

In 1870, by an order of the Ministry of Finance, the Kharagi and Ushuri taxes were increased by 10 per cent. to cover the cost of maintenance of the irrigation works. In the same year the Ushuri taxes were classified afresh.

In 1871 the temporary increase of 1868 was made permanent. As the classification of Ushuri taxes in 1870 resulted in a decrease of 60,000*l.* per annum in the land tax, the Ushuri taxes were increased, and the maximum for Lower Egypt became 77 piastres per acre and for Upper Egypt 51 piastres per acre.

In 1880 the Ushuri taxes were augmented by 150,000*l.* per annum, and the maximum in Lower Egypt now became 112 piastres per acre and in Upper Egypt 102 piastres per acre.

In 1884 some of the southernmost provinces of Upper Egypt were permitted to pay their taxes in kind.

Owing to urgent appeals for a reduction of taxation from the southernmost provinces of Egypt, an examination of these provinces was made by Sir Elwin Palmer, Financial Adviser, at the beginning of 1890.

In 1891 the Kharagi taxes of the southernmost Mudiriehs were reduced by the following amounts :—

Nubia	£14,914
Kena	103,282
Geeza (a part of)	9,184
A total of	£127,380

In Kena and Nubia the taxes were reduced by 33 per cent. generally, and by 50 per cent. in special cases. In Geeza the reduction was 25 per cent.

In 1892 the taxes of those lands which had formerly been put up to auction were fixed at Kharagi rates, and all fractions were removed from both Ushuri and Kharagi taxes. The Kharagi taxes of the following Mudiriehs were reduced as follows :—

Girga	by £81,651
Remainder of Mudirieh Geeza	by 34,173
	£115,824

In Geeza and Girga the reduction amounted to 20 per cent.
In 1894 the Kharagi taxes were reduced in the following Mudiriehs :—

Assiout (with the exception of Ibrahimia Canal irrigated lands)	by £67,667
Minia (ditto)	by 19,832
A part of Beni-Suef (ditto)	by 1,847
Total	£89,346

In Assiout the reduction amounted to 17 per cent., in Minia to 14 per cent., and in Beni-Suef to 13 per cent.

Between 1891 and 1894 the Kharagi taxes of Upper Egypt were reduced by 332,550*l.*, or 17 per cent., and at the end of 1894 the taxes stood in round figures as follows :—

—		Upper Egypt	Lower Egypt	Total
Kharagi	acres	1,717,000	1,975,000	3,692,000
„ taxes	£	1,660,000	2,430,000	4,090,000
„ tax per acre	£	·96	1·23	1·07
Ushuri	acres	472,000	1,073,000	1,545,000
„ taxes	£	165,000	525,000	690,000
„ tax per acre	£	·36	·49	·44
Total	acres	2,189,000	3,048,000	5,237,000
Total tax	£	1,825,000	2,955,000	4,780,000
Tax per acre	£	·83	·97	·91

The registered land, exclusive of that held by the Daira Sania and State Domains Administrations, was thus classified in 1894 :—

LOWER EGYPT.

	Kharagi	Ushuri	Total
Land paying taxes of—	acres	acres	acres
From 175 to 165 piastres *.	6,302	..	6,302
„ 164 to 150 „	831,124	..	831,124
„ 149 to 125 „	435,190	..	435,190
„ 124 to 100 „	204,485	37,948	242,433
„ 99 to 75 „	165,986	243,244	409,230
„ 74 to 50 „	83,434	177,059	260,493
„ 49 to 25 „	30,074	176,564	206,638
„ 24 to 0 „	376,875	166,470	543,345
Total	133,470	801,285	2,934,755

* 100 piastres = 1*l.*

UPPER EGYPT.

	Kharagi	Ushuri	Total
Land paying taxes of—	acres	acres	acres
From 159 to 150 piastres* . .	423	..	423
„ 149 to 125 „ . .	52,454	..	52,454
„ 124 to 100 „ . .	799,877	98	799,975
„ 99 to 75 „ . .	470,504	911	471,415
„ 74 to 50 „ . .	179,493	111,826	291,319
„ 49 to 20 „ . .	45,395	126,041	171,436
„ 19 to 0 „ . .	35,462	74,718	110,180
Total	1,583,608	313,594	1,897,202
Grand total . . .	3,717,078	1,114,879	4,831,957

It has been already stated that the lands are classed as "*Kharagi*" or "*Ushuri*" in the Government registers. The Kharagi and Ushuri lands are again subdivided into "*Nihai*," "*Moakat*," and "*Ger Marbût*." Nihai comprises all the lands which pay the final taxes of their category. A single "hod" may contain various categories of Nihai taxed land. Moakat comprises the lands which pay temporary taxes of various kinds and whose limit of taxation is the final, or "Nihai" tax of their hod, though some hods have no "final" land. Land reported as uncultivable passes under the generic name of "Ger Marbût," literally "without tax," in the Government registers. After that land, left outside the Cadastre begun in 1813, had been granted away and made Ushuri, taxes were by degrees imposed upon that part of it which was reclaimed and cultivated. No tax was imposed upon the part unreclaimed, which figured as "Ger Marbût" up to March, 1894, when it was subdivided. That part of it which could be reclaimed by individual effort was taxed according to a light and gradual scale, and so entered the category of "Marbût" or tax-paying land. The balance which could not be brought under cultivation by individual effort, and which needed public works to enable it to be brought under cultivation, still remains in the general category of "Ger Marbût."

In addition to this "Ger Marbût," consisting, as explained above, of land irreclaimable and uncultivable except by the agency of public works, other land is brought under the "Ger Marbût" category by the operation of the "Talaf" decree of 1889. This decree does not deal with land that has never been cultivated, but, on the contrary, with land that has been cultivated but has gone out of cultivation, and in every case before exemption is

* 100 piastres = 1*l*.

granted the Public Works Department has a voice in determining whether the application for relief should, or should not, be forwarded to the Finance Department. Land cannot remain "Talaf" without periodical revision.

The base of the existing land tax settlement of Egypt was fixed in 1864. Since then the conditions of irrigation, drainage, transport, population and tenure have undergone material changes. These changes of conditions have gradually resulted in rendering the incidence of taxation exceedingly light in some places and abnormally heavy in others. One of the first acts of Sir Elwin Palmer, on becoming Financial Adviser to the Khedive, was to recommend heavy reductions of taxation in the southern Mudiriehs of Upper Egypt, and lighter reductions in others. As already remarked, these reductions amounted to no less than 332,550*l.* in all, and were effected between 1891 and 1894; and since the Government at that time had in its possession no estimated valuation of the country, it reduced the taxes *en bloc.* This system answered fairly well in the purely basin tracts of the south, where, as a rule, the taxes bore some ratio to the rents. When, however, petitions for reduction came from the north and from the perennially irrigated tracts, no such procedure was possible, and at the beginning of 1895 the Government, on the advice of Sir Elwin Palmer, decided to undertake a land rent valuation of the whole of Egypt and compare it with the existing taxation previous to readjusting the land tax. This valuation was begun in April 1895, and the Government appointed me Director-General of the operations.

The work was performed by ten commissions. Each commission consisted of two official and two non-official members. The valuation was completed by April 1897. Since this valuation was made the Egyptian Government has asked the consent of the European Powers to the reduction of the land tax to one-third the renting value assesed by the commissions on all lands which pay over one-third their renting value. The reduction will amount to 216,000*l.* per annum, and the consent of the Powers has been obtained. Meantime Mr. Gorst, the new Financial Adviser, intends utilising the valuations and applying them to the new Cadastral maps as they are finished, so that before long the land tax of Egypt will be put on a rational and healthy basis.

I extract the following facts from my note-books, as they bear on the agricultural questions before us:—

"One of the main *factors governing the renting values of the land* was found to be the wealth or poverty of the resident population. Among the many causes which have helped in recent years to add to the wealth of the fellaheen and to raise the rents over the whole of Egypt, the abolition of the corvée and the substitution of paid for unpaid labour have held a high place. While improved irrigation has, as a matter of course, played the principal part, the recent very appreciable lowering of the taxes in the Southern provinces and in Geeza has given a further

impetus to the rise of rents in the provinces affected. If a comparison be instituted between the prosperity and taxable capacity of to-day and what it was ten years ago, it will be found that probably no part of Egypt has improved more than the Nile valley south of Abutig, near Assiout, where the abolition of the corvée, improved irrigation, and a lowering of the taxes have gone hand in hand.

Where extensive contiguous estates were owned by non-resident landlords, the resident population was found to be poor and the rents comparatively low. Especially was this the case where the lands were let to non-resident middle-men, who sublet to the fellaheen at rack rents. Such estates have benefited far less than others from all that has been done in recent years; and not only have their own rents remained low, but they have also depreciated neighbouring properties owing to the excessive poverty of their resident population.

In the well irrigated basins of upper Epypt, especially in Girgà and Southern Assiout, and in the Sêfi tracts of the whole of Egypt, where drainage was not essential, the *fellaheen proprietors* who paid taxes direct to the Government were found to be possibly the most contented and prosperous agricultural community in the world. Their wants were simple, their taxes were low, and now that the canal clearance corvée had been abolished, they were more often buyers than sellers of land. It was not to be inferred from this that taxes were nowhere oppressive, for they certainly were, but on restricted areas and confined to the badly irrigated or badly drained tracts.

The proximity of manures in the deserts or in ancient ruins was found to exert a strong influence on rents. The land-tax adjustment commissions had begun to collect a mass of information on this subject, when Mr. Fuller, C.I.E., was invited by the Egyptian Government to take up the question of manures. His exhaustive examination of the question covered the whole ground of enquiry and was embodied in a report which he submitted to the Government. His main arguments might be thus epitomised: 'Nile water, though exceedingly rich in potash, which constitutes the principal food of leguminous plants, is singularly poor in nitrogen, on which cereals depend. Indeed so low is the proportion of nitrogen in Nile water that only choice localities which receive many times their proper share of red water deposit can grow cereals year after year, or be double cropped, without the aid of manure. The bed of the Nile rises gradually at the rate of a few centimetres per century, and the rise of the river bed is accompanied by a corresponding rise of the lands irrigated by the red muddy water let into the basins. This rise spread over the whole area represents an amount of deposit which does not contain a fraction of the nitrates needed for cereals. Basin irrigation thoroughly washes the lands, keeps them free from injurious salts, and covers them annually with a deposit of mud which suffices generally for crops of leguminous plants and cereals sown in rotation in alternate years. In some basins the deposits are so rich that two crops can be produced per annum without manure, but this is exceedingly rare; and, generally speaking, a free application of manure is a necessity for a double cropping and for cereals in the poorer basins. In Upper Egypt this manure is almost wholly obtained from the nitrates in the deserts between Halfa and Kena, and from certain ancient ruins such as Abydos, Ashmunên, Medinet, Fayoum, and others. South of Kena the supply from the deserts is inexhaustible; but to the north of Kena the ancient ruins are being gradually exhausted, and, morover, supply but a fraction

of the area requiring manure. In Lower Egypt and the more prosperous parts of the Mudiriehs of Kena, Girga, Assiout and Geeza, where cattle are neccessary for lifting water and very numerous, farmyard manure is very plentifully used.' By no system of irrigation would it be possible to so increase the deposits in the basins generally that they could be independent of manure over their whole area. If an increase of this kind were attempted, the land would rise so much faster than the bed of the Nile that in all but the highest floods the water would eventually fail to reach the level of the basins; and we should have years of excessive fertility alternating with years of drought. Looked at in any light, therefore, it may be stated that the manure question in Egypt occupies, and will always occupy, a position inferior only to irrigation.

The selling price of land was found to vary from sixteen years' purchase in the wealthy villages which enjoyed perfect irrigation and drainage, to twelve years' purchase in ordinary tracts, and even eight years' purchase where irrigation was precarious and drainage deficient. The mean was fourteen years."

If one is desirous to further study the question of *manures and of the nitrate deposits* in the deserts south of Kena brought to the notice of the Egyptian Government by Mr. E. Floyer, of the Telegraph Department, reference should be made to a paper entitled "Nile Cultivation and Nitrates," read by Mr. J. B. Fuller, C.I.E., before the Agricultural Society of England, and embodied in their third series, vol. vii. part 4, 1896. A pamphlet entitled "Manures in Egypt and Soil Exhaustion," by Dr. Mackenzie and Professor Foaden, of the Cairo College of Agriculture, printed by the Egyptian Government in 1896, and another on "Cotton Culture in Egypt," by Professor Foaden, of the College of Agriculture, published by the United States Government as Bulletin No. 42 of the United States Department of Agriculture Office of Experimental Stations in 1897, contain a mass of the most valuable information. The Report of the Egyptian State Domains Administration for 1895 also contains much information about cotton cultivation, collected by Mr. Carey, of the Domains Administration. In Professor Foaden's pamphlet the different kinds of cotton and other worms are also fully considered. All the recent reports of the State Domains Administrations are mines of information on all agricultural questions.

During the six years that I had charge of the Second Circle of Irrigation I had frequent opportunities of examining into the question of the *cotton worm*. The general conclusion I came to was the following:—

"*The cotton worm* is one of the skeletons in the cupboard of the Egyptian agriculturist. The loss to Lower Egypt caused by its depredations has amounted in some years to fully 2,000,000*l.* There are two kinds of cotton worms, which are both well known. The first is a caterpillar which makes its chrysalis in the earth; and the other is a maggot which appears in blighted pods. During winter these worms are not to be seen anywhere. The chrysalis apparently hibernates. About the end of May, when the clover is everywhere in flower and the cotton plants young and tender, thousands of moths of a dusky colour are to be seen hovering over the

clover at night, and laying their eggs either on the leaves of the cotton plants or in the clover. Boys and men are to be seen busily engaged picking off the leaves covered with eggs. About five days after the eggs are laid they are hatched, and the young worms begin eating the cotton leaves or the clover; and in about 25 days, having attained a length of about two inches, they enter the ground at the roots of the cotton plant and change into the chrysalis state. After an interval of 15 days the moth appears a second time, feeds this time on the cotton flowers, lays its eggs, and dies. The young caterpillars or worms enter the young buds and flowers and destroy them, and then devour the leaves as they grow larger. They run the same course and appear again in August, when they cause very serious damage indeed. As a moth lays many hundreds of eggs, and about two months complete a cycle, their power of increase is enormous. Finally the worms appear in the young clover in October and November, and often eat down whole fields, which have to be resown. There is a respite in winter. This worm is not the only plague, there is also the other, which was called a maggot. Whenever there are heavy fogs in July or August, a large number of pods seem to be blighted and covered with dark spots; and if a pod be opened, it will be found, if black outside, to have inside of it little worms of a different kind to those which come from the chrysalis.

For the worms which appear inside the blighted pods like maggots the only remedy appears to be an application of a sufficient quantity of quicklime to the fields. The soil of Egypt, which in the basins contains a fair proportion of lime, is very deficient in lime in the lands long deprived of basin irrigation. To these a liberal application of lime would prove very beneficial. As much as fifty loads are applied profitably to an acre of land every fifteen years in certain localities in England, and the same liberal allowance would be attended with marked profit in this country, though a much smaller application would also prove beneficial. A ton of lime costs on the average 1·80*l.* in the Delta.

For the other cotton worm or caterpillar, there are periods in his multiform existence when he may be easily attacked. After a long hibernation, the chrysalis changes in May into a caterpillar, which feeds on the clover flowers, while it prefers shade and dampness, eats at night, needs a friable soil at the roots of the trees in order to burrow in during the day, and to change into a chrysalis in when its course is run; and the chrysalis is dormant in the earth for about a month in July and August. The first year in which worms were troublesome in Egypt was 1879, when the Nile in the summer following the great flood of 1878 was very high, so high indeed that not a single gate was lowered at the Barrage, and yet the surface of the water was nearly as high as it was in 1885, when the Barrage was holding up 3 metres. Previous to 1884 there was very little water available for irrigation in the months of March and April, as the Barrage gates were not lowered until the Nile gauge fell to 12·50 metres; and, the canals also being full of silt, there was seldom any water available for irrigation till the 15th of April, when the cotton sowing began. The consequence was that clover was cut about three times and then allowed to die off; now it is cut some five times, lives on well into June, and the clover flowers supply the food to the moth and the clover leaves to the worms till the cotton plants are big enough to shelter the latter.

Some agriculturists think that the Egyptian cultivators sow the cotton too

close; they produce so much shade and dampness, and exclude so much air, that it is not to be wondered at that once the worm enters it is very difficult to dislodge it. If, instead of sowing the plants about 30 centimetres apart, they were to sow them some 60 centimetres apart, and when the plants were 30 centimetres high they were to make an application of manure to the roots of each individual plant, the very best results might follow.

The worm, which eats during the night, seeks shelter during the day in the friable soil of the ridges on which the cotton plant is sown. These ridges are the nursery and bedroom of the cotton worm. They are thrown up because the irrigation of the rills between the ridges is much more economical in summer than the irrigation of the whole field; they besides allow air to enter the ground. The worm which appears in June and July cannot well be fought with except by letting the clover die off in April, and by manuring and liming the fields. When, however, the July worms have changed into chrysalises and entered the ground, it would be easy to level the ridges; and at the beginning of the flood, early in August, thoroughly flush the field with red slimy water, and bury the chrysalises for good and all. Frequent applications of red muddy water in August would complete the destruction of the worm in this stage of its existence. The August and September depredations, which are the worst of all, would thus be avoided, and the young clover fields in November would be free from the worm."

The above was written in 1888. Writing to-day I may say that the ordinary method of combating the worm nowadays is to get gangs of men and women and children into the fields, to pick off the leaves covered with eggs and to destroy them. After many plans have been tried, this one has nearly everywhere been accepted as the most successful.

The following selections are from notes made by me in 1892 during a three weeks' study of irrigation and reclamation in the valley of the Po. They contain much information about very extensive drainage and reclamation works which may be of practical use in this country, as the mouth of the Po in summer has a climate not very different from that of the sea board of the Delta. These notes might have followed Chapter VIII.

"From Ferrara eastwards to the Adriatic the land is very low lying, but very carefully cultivated. The principal crop is hemp, with rows of mulberry trees and vines at intervals of about 50 metres. The manure which is applied to the fields is principally made of bones and blood and the chippings of horse hoofs. Where the spring level is ·75 metre below the surface of the ground the crops are excellent. If the spring level is under ·75 metre but over ·25 metre the land is converted into rich pastures. If it is intended to convert pasture land into arable land, the spring level has to be lowered by drainage cuts and pumping. There is an enormous extent of land just above and below spring level in the valley of the Po which has been improved and reclaimed by drainage. Some pumps serve 500 acres, some 10,000 acres, while the mean area on a pumping station is 2500. One low-lying tract which I inspected near Porto Maggiore was 33,500 acres in extent, and was drained by 9 pumping stations. To the east of it lay the 'bonifica della Galare,' of 30,000 acres, drained by one pumping station, while at Codigoro I saw

COMPARATIVE RESULTS OF LAND RECLAMATION AND DRAINAGE IN THE VALLEY OF THE PO NEAR FERRARA.

	Name of Commune	Area in acres	Improvement	Water Drained off by Pumps, cubic metres per second	Coal Consumed, in tons per annum	Annual Cost of Maintenance, including coal, £	Horse-Power		Cost of Reclamation Works in £	Compensation to High Lands, £	Works Benefiting High Lands and Drained Lands alike, part paid by drained area, £
							Effective	Indicated			
1	Benore . .	5,523	..	2·6	190	480	67	132	17,986	1,258	2,988
2	Cersallo. .	1,708	..	·8	77	208	23	45	5,303	..	676
3	Bevilacqua .	2,983	..	1·4	104	320	37	72	9,752	166	..
4	Martinella .	5,684	..	2·4	190	480	68	132	16,002	1,461	..
5	Trava . .	1,235	..	·6	64	188	18	34	5,223	..	..
6	Benvignante .	5,785	..	2·7	190	480	66	132	17,233	..	1,501
7	Sabbiosola .	2,567	..	1·2	87	224	28	55	8,708	..	1,221
8	Monte Santo .	2,452	..	1·2	77	208	22	44	7,675	..	2,343
9	Campo Circo .	5,658	..	2·6	190	480	68	132	16,999	..	2,220
	Total .	33,595	..	15·5	1,169	3,068	397	778	104,881	2,885	10,949

Last three columns together: £118,715

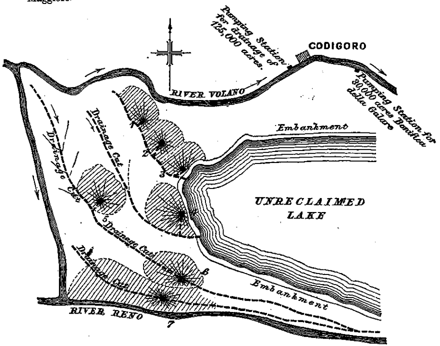
Rows 1–4: Cost of works comes to 3·5*l.* per acre.

Rows 5–9: Maintenance charges per annum come to 1*l.* per 10 acres.

the largest pumping station in Italy, which drains 125,000 acres. This last tract, however, was too extensive, and the *most economical area to drain with one pump is* 2500 *acres*. Through the kindness of Mr. Borsari, of Porto Maggiore, I have been able to tabulate the cost of reclamation and improvement of 33,500 acres.

It will be seen from the table that there are 9 pumping stations, while there is one Chief Engineer, Mr. Borsari, 4 Assistant Engineers, and the usual staff of engine drivers, &c. Mr. Borsari informed me that if the drainage area is under 1000 acres in extent, the effect of the drainage is immediately felt, while if the area is 5000 acres it takes two years to appreciate the benefit. I saw the foundation being put in of a new pumping station, and it struck me that if ever similar work was undertaken in Egypt, it would be far better to obtain the services of experienced men from Italy than to employ the first man who offered himself, as is too often done in Egypt. The work under construction was solidly and cheaply designed with a very free use of arches. Nearly all the recent engines and pumps were centrifugal.

The accompanying sketch gives a fair idea of the positions of the pumping stations for the tract of 33,500 acres of land improved by drainage near Porto Maggiore.



The whole of the drainage and pumping has been and is done at the expense of the proprietors. The Government drains are all in embankment.

The River Volano, in high embankment, is one of the drains of the district. The lands are all drained by pumping into it or into one of the other rivers.

Referring to the table on page 395, it will be seen that the cost of improvement and reclamation of 33,600 acres came to 119,000*l.*, thus made up :—

Earthwork in drains . .	£29,000	Masonry costs 90 piastres per cubic metre. Earthwork, 2 piastres per cubic metre.
Masonry	29,000	
Pumping machinery . .	26,000	
Compensation . . .	13,000	
Projects, &c. . . .	5,000	
Contingencies . . .	17,000	
	£119,000	

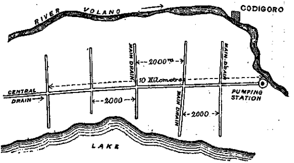
The actual net benefit to the lands drained is as follows :—

High land	16 piastres per acre per annum.
Low land	24 " " "
Mean	20 " " "

So that the net profit on 33,600 acres at 20 piastres per acre per annum is 6720*l.*, or 6 per cent. on the money spent, with the insurance that the lands will *not* deteriorate, and as population increases, and silk worm culture and vines are gradually introduced, the land will take its place as first class. The best land east of Ferrara lets at 2·50*l.* per acre per annum, while the lands we are now treating of have been up to the present improved as follows :—

Best land	from £1·60 to £1·76	per annum.
"	" 1·50 to 1·60	"
"	" 1·30 to 1·50	"
Reclaimed land	" ·50 to 1·00	"
"	" ·30 to ·75	"

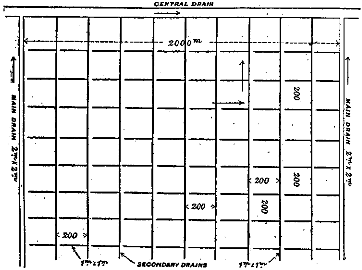
The depth of the drains is so regulated that the lowest lying land must be ·80 metre above water level in the drain. It will readily be understood that the larger the area the longer the drains, and therefore the greater the loss of slope and the height to which the pumping engine has to lift.

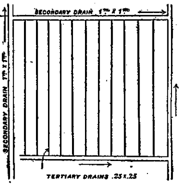


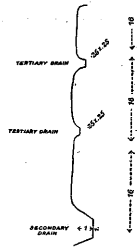
Land reclamation for Codigoro.—One of the satisfactory reclamations in the valley of the Po is the Bonificazione della Gallare of 30,000 acres, of which 10,000 were originally covered by the sea or lakes at the mouths of the Po. The principle on which the reclamation has been carried out is as follows :—

The sketch on page 397 gives the main drains tailing into the central drain.

The main drains are 2 metres wide at bottom and 2 metres deep. The central







drain increases in section from the head to the pumping station, where it is 20 metres wide and 2 metres deep.

The space between two main drains is divided into spaces of 200 metres square each by secondary drains, as in the sketch. These secondary drains are all 1 metre deep and 1 metre wide at bottom.

Each of these smaller squares of 200 metres × 200 metres is cut by 12 drains (each drain ·25 metre deep and ·25 metre broad) into long strips each 16 metres wide; so that a cross section of the ground is as at bottom of page 398.

The land was very well drained and was principally under wheat when I saw it. The wheat as a rule was excellent, but there were extensive tracts of peat soil where the wheat was poor and weeds and reeds abundant.

One of the main difficulties about reclamation is the reluctance of the peasantry to settle in these low lands. Once they can be induced to settle, mulberries and vines follow as a matter of course, and success is assured.

At the pumping station there were two old Dutch pumps (Rade scoop wheels) worked by engines of 400 horse-power, and a 48″ 'Gwynnes' Invincible pump worked by an 80-horse-power engine. This latter did the whole of the work as a rule. It lifted 1 cubic metre per second 4 metres in height, and gave a constant discharge. After heavy rain all three pumps were worked, and as the lift decreased considerably they did 8 cubic metres per second between them. The engineer in charge of the station, a Dutchman, was loud in praises of the Invincible pump."

This chapter will be closed with a quotation from my report on "Perennial Irrigation and Flood Protection." The question of *pisciculture* is well worth attentive study by the Egyptian Government.

"We have so far considered only the direct gains from perennial irrigation; we now come to a new industry which has yet to be introduced into Egypt and which accompanies such irrigation in the sub-tropical regions of China, I mean pisciculture. I preface my remarks by a quotation from General Tcheng-ki-tong's paper read at the Paris International Congress in 1889: *

'I may add that, without these gigantic irrigation works, the Chinese could never have carried to such a point of perfection one of their most important industries. I speak of pisciculture. Thanks to the abundance of water, the whole of my countrymen, instead of contenting themselves with covering with their fishing boats, the seas, rivers and lakes of our country, have devoted themselves to the breeding of fish. The spawn is everywhere carefully collected; far from leaving it to take its chance the peasant gives this source of wealth a safe shelter in some spot where a perennial supply of water can be assured. The irrigation reservoirs team with fish. During winter the rice fields are fallow; the water is let into them and they are instantly full of carp. This industry allows us to make fish a considerable factor in the food of our people. The fish are either eaten fresh; or salted and dried, they are despatched to all parts of the Empire and sold at a price which is remunerative though it is exceedingly cheap.'"

* 'Congrès de Utilisation des eaux,' Paris, 1889, p. 320.

CHAPTER XIII.

ADMINISTRATIVE AND LEGAL.

Public Works expenditure—Cost of Nile protection—The earthwork maintenance corvée—History of the corvée—Decree of 25th January, 1881—Injustice of the corvée system—Nubar Pasha's action—Sir Colin Moncrieff's reports for 1884, 1885, 1886, 1887, 1888 and 1889—Earthwork maintenance corvée abolition—Evils of underpaid Egyptian employés—Decrees and regulations concerning irrigation—Canal Law of 1890, modified by decree of 22nd February, 1894—Decree of the 8th March, 1881, for regulating water-raising machines—Ministerial order—Decree of the 12th April, 1890, concerning watercourse heads, and machines other than pumping engines—Articles in law codes referring to irrigation.

THE Public Works of Egypt, consisting of canals, roads and buildings, are administered by a central establishment consisting of a Secretary and Under Secretary of Public Works and a central office costing 33,000*l.* per annum. The Irrigation Department is under two Inspectors-General of Irrigation having under them Inspectors of Irrigation, and Chief and District Engineers. The irrigation budget was subdivided as follows on page 26:—

Establishment	£70,000
Contingent charges	25,000
New works	60,000
Maintenance of masonry works	55,000
Nile protection works	25,000
Draining Lake Mariotis	10,000
Earthwork maintenance	400,000
Total	£645,000

In addition to this is the corvée or forced labour gangs who guard the Nile banks during flood without payment, and have to provide Indian corn and cotton stalks for protecting the banks against the wash of the waves. From figures given in Chapter X., the mean annual expenditure on Nile corvée and protection may be put down at 150,000*l.*, which brings the total to 795,000*l.*

The sum allowed for original works permits of the annual construction of a certain number of new syphons and regulators. The masonry works themselves, which were previously in a complete state of disrepair, are being gradually put into working order. The people themselves are naturally untidy and indifferent about the appearance of their works, and it will be many years before ideas of neatness and tidiness will be inculcated. A com-

parison of the existing masonry regulators, canals and banks in Egypt with similar works in India is absolutely out of the question. The permanent protective works on the Nile, such as stone spurs and the provision of stakes, absorb the money provided by the State.

When Sir Colin Scott-Moncrieff took charge of the Public Works of Egypt in 1883, the whole of the earthwork maintenance of the country was performed by forced labour or *corvée*. This earthwork maintenance corvée was finally abolished in December 1889, and was one of the most creditable performances of the British occupation of the country. The whole question will be fully treated in this book.

The *corvée* is the name given to the forced labour which, from time immemorial, was annually employed to clear the canals and strengthen the dykes of the basins during winter and summer, and to guard the banks during flood. While there was nothing but basin irrigation in Egypt the system, in theory, was not a bad one, as during the working months there was absolutely nothing else for the agricultural population to do except repair the dykes, clear the canals, or protect the banks. The whole community was interested in the canals supplying plenty of water to the basins, and the burden of ensuring this fell properly on all. With the introduction of perennial canals and irrigation in the time of Mehemet Ali the natural abuses, which must always have accompanied the system, were aggravated by new and special abuses. The whole agricultural population was employed to clear the deep perennial canals, though only a limited number were interested in them. Then, also, began the pernicious habit of moving the corvée from province to province, and keeping them at work through the whole of the summer, while at the same time the presence of water in the deep canals made the absence of the peasantry from their fields doubly trying to them. Said Pasha even employed the corvée on the Suez Canal, while Ismail Pasha used contingents of corvée from all the provinces of Egypt to dig the Ibrahimia perennial canal in Upper Egypt—a canal constructed almost entirely for the benefit of the Khedivial private estates. The programme of work sketched out yearly for the corvée was so extensive that they never completed a fraction of the works before the arrival of the flood made them hurry off to guard the banks. There was no difference made between maintenance and original works. These public abuses, though great, were exceeded by the private abuses, unsanctioned by the State. As the summer irrigation increased, and the value of the cotton crop began to be appreciated, the presence of the men in their own fields began to be more valued; advantage was taken of this by the larger proprietors to keep all their own tenants at home, and make the poorer peasantry, known locally as fellaheen, do all the work; while ministers and high officials not only sent none of their own tenants to the corvée, but employed, each of them, some 200 or 300 of the regular corvée to work on

their private estates. The fellaheen were thus not only compelled to work throughout half the year at canal clearances, but were not allowed to reap any of the fruits of their labours.

The corvée were expected to work about nine months per annum: for the six months from the 15th January to the 15th July they worked at canal clearances and repairs of banks, for the three months from the 1st August to the 1st November they guarded the Nile banks. They had to supply their own tools, such as spades and baskets; they had to provide their own commissariat; and, during the winter and summer, they had to sleep on the ground, moving from encampment to encampment without any shelter except that provided by trees and shrubs. During the flood they built booths for themselves on the Nile banks, and had to provide, at their own cost, lanterns at intervals of 50 metres, and whatever brushwood was necessary for the protection of the banks along the whole length of the Nile, on both banks.

The official basis of the calculation of corvée used to be the census of the male agricultural population, between the ages of fifteen and fifty, which Mehemet Ali took in 1847. The basis now is a certain proportion of the male agricultural population according to the last census. In Mehemet Ali's time, one-fourth of the number were called out every 45 days through the summer, so that the whole corviable population worked on the canals during the 180 days that the works lasted. This proportion was gradually reduced as the Government officials became more lax, until in 1881 about one-eighth of the whole number were called out to work every 45 days. The balance represented the large number of men who had freed themselves from corvée. The Khedivial decree of the 25th January, 1881, laid down the terms on which certain privileged classes could redeem their tenants from the corvée. Since the decree laid down no penalties for those who neither sent men to the corvée nor paid their redemption money, the natural result was that scarcely anybody paid any redemption money except the State Domains Administration. The Khedivial decree of the 25th January, 1881, is the first official document relating to the corvée, and is given here in full:—

DECREE OF 25TH JANUARY, 1881,

Regulating the Works on the Nile and its Canals.

ARTICLE I. The public works enumerated below are, and will remain, at the charge of the State:—

(*a*) The masonry works, which are of benefit to one or more provinces, existing or to be made, on the Nile and its branches, on its banks, on its principal canals, on the banks of the basins of Upper Egypt, and other banks of general interest.

(*b*) Dredging, comprising all charges of purchase, maintenance, and working of the plant.

(*c*) The furnishing and transport of materials, such as stones, wood, sacks, necessary for the public interest, whether for the conservation of banks and regulators or for the closure of dams and regulators and canal sluices.

II. The quantity and the cost of the works and materials, which shall be at the charge of the State, shall be determined each year in conformity with the rules and regulations established or about to be established concerning them.

The total amount and cost shall be entered in the budget of the Public Works Ministry. But always in whatever concerns the works of the Ibrahimiyâh Canal, the proprietors of the lands affected shall, until the completion of the cadastral survey, remain liable to repay the Treasury the sum which it has advanced for these works.

III. The maintenance or construction of masonry works made or about to be made on the canals or banks, and benefiting either several villages or one or more districts, or one village, or one private property, falls on the proprietors of the lands benefiting by their use or construction.

IV. The following works are constructed and maintained at the cost of the general public:

(*a*) The earthwork, whether of excavation or embanking, and the clearance by hand, whether they affect one or more provinces, or the villages of one or more districts, or a single village or a private property.

(*b*) The watching of the banks and other works during the period of the Nile flood.

(*c*) The handling and working of materials destined for the preservation of banks, and works, and regulation.

The Public Works Councils class these works as follows:—

Works of general benefit; works of restricted benefit (Mushtarak); works of private benefit; and divide them between the inhabitants of the provinces and districts.

The works of general and restricted interest are those for which corvée ransom may be paid.

V. The corvée ransom is due from all male inhabitants of the country, of sound health, between the ages of fifteen years and fifty years, with the exception of those indicated as exempt in the next article.

VI. The following are exempt from corvée ransom:—

1. The Ulemas (persons learned in the Qurân). Fikis (those who recite the Qurân). Persons engaged in teaching. Students in the mosques and schools. Persons attached to charitable institutions, Takiyahs (shrines), convents, and hospitals.

2. Persons in the service of the mosques, tombs and holy places possessing regular titles.

3. Priests, monks; rabbis, persons attached to the service of the churches, temples, cemeteries of the various sects, furnished with regular titles, similarly.

4. People having professions or trades who pay professional taxes, and who exercise their calling; also fishermen and boatmen.

5. The watchmen of the villages and hamlets, &c., recognised by the Mûdir of the province.

VII. Every individual liable to forced labour (prestation) can free himself by furnishing a substitute.

The following can free themselves by paying a cash ransom:—

(*a*) In the hamlets or settlements (Esbahs) which have always existed as isolated, without being a part of any of the neighbouring villages, the inhabitants not reckoned in the census of the villages.

(*b*) Landowning Bedouins and cultivating Bedouins heretofore exempt from the forced labour works.

(*c*) The inhabitants of the villages working on the lands of the State Domains and Daira Sanieh in Lower Egypt, in the villages where these Administrations have more than 100 acres, on condition that the lands are not let, and under the reserve that the number of men ransomed out of each village shall be limited to those required for cultivation.

For the villages in which rice is the predominating crop, and those which have been, like the rice villages, the objects of a special measure as regards the adjustment of the land tax, the forced labour is obligatory; but, in the annual division of work among the inhabitants of the provinces, there will be imposed on each man of these villages only the half of the quantity imposed on a man of other villages.

VIII. The cash payment of the ransom in the cases in which it is allowed, is fixed in 1881 at 120 * (one hundred and twenty) piastres per man in the provinces of Lower Egypt, and at 80 † (eighty) piastres in those of Upper Egypt.

After the year 1882 the amount of ransom per man shall be fixed annually, and notified to the Mûdiriyahs by the Minister of Public Works, one month before the commencement of the works. It shall be fixed after consideration of the nature and quantity of work to be done, and the time during which they are required to be executed.

IX. The Minister of Public Works can suspend, for any reasons he judges to be of general benefit to the works, the permission to ransom granted in Art. 7; he can equally, in the case when he judges it possible to substitute for forced labour mechanical labour or labour by contract, authorise in a general manner the cash payment of ransom in one or more Provinces.

X. The sums received in each Mûdiriyah as corvée ransom will be entered in a special register, and deposited in the treasury of the Mûdiriyah, and held at the disposal of the Minister of Public Works.

These sums can only be spent on works which have for their aim the reduction or the suppression of forced labour.

XI. It devolves on the Minister of the Interior to summon and keep on the works those subjected to forced labour.

A Khedivial decree, dated 12th March, 1882, issued under the influence of Araby Pasha, allowed Arab settlers in Egypt to redeem themselves like the inhabitants of the hamlets (Ezbahs), while the Bedouins were exempted altogether from the corvée. It was also decreed that a commission should be appointed to lay down rules as to how the redemption money to be paid by the hamlets was to be calculated. A committee was appointed, under the presidency of Ismail Pasha Yusri,‡ which recommended that every hundred acres of land attached to the hamlets (Ezbahs) should pay for

* 1·20*l.* † ·80*l.* ‡ Ismail Pasha Yusri received his education in England.

eight persons. This would have meant 9·6*l.* per hundred acres in 1881. This recommendation would probably have been embodied in a decree had not the troubles of 1882 intervened. This principle to the corvée tax being on the land, and not on the individual, came to the front the moment the party of Araby Pasha were in power. On the return to power of Ministers who represented the large landholders, the opposite principle of the tax being on the individual, and not on the land, was of course insisted upon. These latter asserted that it was not fair to put the corvée tax on the land, because the land tax included a small irrigation tax. Considering that the land tax contained an irrigation tax which was insufficient, it would apparently have been more reasonable to raise it slightly, say 3 or 4 per cent., than to make a poll tax of the balance of it. If the poor had refused to work, and if there had been no means of compelling them, they would have lost next to nothing, while the rich pump owners and landholders would have suffered heavily.

Taking advantage of the decree of 1881, every man of any position freed himself from corvée without taking the trouble to pay the redemption tax, while the *whole* of the corvée fell on the poorer classes. Indeed, no man who owned more than five acres of land went to the corvée. Early in 1885 the fellaheen of Kafr Sheikh district appealed for an inquiry into the corvée of their district, and on the Government making the inquiry, it was found that although the cultivated and revenue-paying area of the district was 145,000 acres, the owners of 33,000 acres supplied the whole of the corvée. The State Domains, who owned 53,000 acres, paid redemption money for half their tenants, while the larger proprietors, who owned 59,000 acres, paid nothing. Legally, the fellaheen ought to have supplied 438 men for 90 days: they were called on to supply 1091 men for 180 days, and actually supplied 800 men for 180 days.

The first tangible relief to the corvée came in 1885, when the Irrigation Department exerted itself to reduce the work to a minimum both by holding up the water in the Nile to a higher level in summer and by working to levels.

Early in that year Nubar Pasha, the Prime Minister, at the request of Sir Colin Scott-Moncrieff, and with the cordial approval of Sir Evelyn Baring, made an advance of 30,000*l.* for making the experiment of clearing certain of the canals of the Menoufia and Garbia provinces by contract, to see if it were possible to do away with the corvée altogether. The experiment proved that hand labour by contract could on all dry work, and on all perennial canals needing less than 40,000 cubic metres each, replace the corvée. Dredging was recommended for the larger canals. Hand labour by contract had so improved in a few years, that perennial canals needing 100,000 cubic metres of work were so cleaned. Early in 1886 Lord Salisbury gave his consent to the expenditure of 250,000*l.* towards the relief of the

corvée, and, for the first time in the long history of Egypt, the State paid towards the maintenance of the canals and banks of the country. Subsequently, Lord Cromer obtained the consent of the Powers to the employment of this sum from the reserves at the disposal of the Public Debt Commission. They refused, however, to find the remaining 150,000*l.* which were needed to completely redeem the corvée, and the Egyptian Government has, since 1890, found the money every year out of sums at its own disposal. The total relief of the earthwork maintenance corvée costs the State 400,000*l.* per annum. The Nile protection corvée has yet to be redeemed. I now give extracts from Sir Colin Scott-Moncrieff's irrigation reports for 1884, 1885, 1886, 1887, 1888 and 1889, to show the steady and determined manner in which the department accomplished this great and beneficial reform.

Report for 1884.—"An army of 125,000 men, working about 150 days, performed about 29,000,000 cubic metres of earthwork. A million of cubic metres can convey little meaning to the ordinary reader, who may be assisted if he remembers that the great pyramid contains 2,400,000 cubic metres.

Mr. Willcocks estimates that the partial use of the Barrage reduced the silt clearance of his canals by about 26 per cent., which, if we assume corvée labour as worth 2 piastres per diem, means a saving to the country of about 26,000*l.*

The number of corvée on the works is equivalent to an army of 92,609 working for 130 days in the year—50,162 in Lower and 42,447 men in Upper Egypt; and this, be it noted, does not include the immense numbers forced to guard the banks of the Nile during the three months of flood, unpaid and unfed by the State which requires their services.

I trust that in two or three years the corvée, with all its detestable abuses, will have disappeared from Egypt.

With the measures now in process of being carried out, silt clearances may be reduced by one half or even more. What remains may be done by dredging, or by ordinary paid labour, the burden forming by no means a heavy rate on the land benefited."

Report for 1885.—"Much discussion took place during 1885 on the question of the corvée, and as I have made this the subject of a separate note, I do not propose to go into very full details here. Mr. Willcocks brought to notice the injustice and the abuses connected with it, and he obtained from the Council of Ministers permission to try throughout the whole province of Gharbieh, and in two of the five districts of Menoufieh, an experiment for its redemption. Assuming a tax of 30 piastres per head on all the *corvéable* of a village, he determined by the census the amount leviable from each village, divided this amount by the area of the village lands, and thus laid the rate on the land.

Supposing, for instance, a population 400 *corvéable* in a village consisting of 2,000 acres. The ransom money would be 400 × 30 = 12,000 piastres, equivalent to a tax of 6 piastres per acre. This was only a voluntary tax however. The corvée redemption could not be made compulsory, and those who did not consent to

it could render their manual service instead. Practically all accepted it, and if it could be made into a law binding on all, high and low, I believe the system would work well and be just. As it was, fighting against all sorts of difficulties, Mr. Willcocks managed this first year to maintain his canals without any corvée, and the new contract system only failed in one case, that of the Sahel canal, to which I have alluded elsewhere.

I should notice, however, that the two central provinces, Menoufieh and Garbieh, are situated more advantageously for such an experiment than the eastern provinces.

Owing to the impossibility of recovering the whole amount of Mr. Willcocks' voluntary rate, the total actually realised was only 22,562*l.*, to which he added 16,726*l.*, the balance of corvée ransom from former years. His total outlay was 53,962*l.*

In Upper Egypt the impossibility of commanding corvée labour required a special grant of 17,576*l.* In Behera a similar grant of 6,000*l.* was required."

Report for 1886.—"In writing the Report of 1885 I stated what measures were being taken for the relief of the corvée. That year there was an outlay of 116,535*l.*, by means of which the unpaid corvée labour was greatly reduced. In 1884 it was equivalent to 165,000 men working for 100 days. In 1885 it was only 125,936 men for the same period. In 1886 the sum spent in corvée relief was 265,066*l.*, and the numbers were reduced to 95,093.

But it would not be fair to ascribe the reduction of corvée labour altogether to the money grant. The fact is, that in former years there was always a great deal of useless labour employed, which we have been able to dispense with, chiefly by using the Barrage, partly by grading the canal beds to a proper slope. Before 1885, when no use was made of the Barrage, the irrigation officer could never be certain that the Nile might not fall to surface level, 11·15 metres, as it did in 1878, and efforts were made to deepen out the canals accordingly, so that they might always take in some water. Since then he has been able to count with fair certainty that the surface level will not fall below 12·80 metres, and there has been no need of clearing the canals deeper. The improvements already made to the Barrage tell chiefly in favour of Menoufieh and Gharbieh. In two or three years' time I trust all Lower Egypt will profit equally. On the other hand while the corvée did much work no longer needed, it was never able to overtake a great deal of work most essential to agriculture, such as the clearing of branch canals and, still more, of drainage cuts. Yearly it was resolved to clear these channels, and yearly at the end of the season they were left undone. Since the money grant has been given these clearances have been made, and it has been thought better than leaving it altogether undone to do this necessary work even by employing so objectionable an instrument as the corvée. On the other hand, great care has been necessary to guard against the undue use of forced labour in addition to the money grant. There exists in the country a fine old Conservative party, who, while they have not the slightest objection to spending in the Provinces whatever money the Government grants, see no sort of reason why so time-honoured an institution as the corvée should not continue.

In three provinces the reduction of the corvée is not satisfactory. In Behera a quite unusual amount of work had to be done. The province is increasing very fast, the *corvéable* population is unusually small. In Keneh and Esneh there are no

English engineers resident. Improvements proceed more slowly there than further north, and I fear the views of the Conservative party to which I have alluded carry more weight there than they should. Strenuous efforts must be made to relieve the corvée of these southern Provinces.

The alternative to corvée labour is paid labour by contract, regarding which, being a new thing in Egypt, many forebodings were uttered. We were assured that the fellah would not work voluntarily; that the contractor possessed of no local influence would never get men, or succeed in clearing the canals within the time required; that they would be oppressive to the people, etc. All these forebodings have proved fallacious. Here, as elsewhere, men prefer to be paid for their labour, and there has hitherto proved no difficulty in procuring them.

On the 31st December, 1885, the Council of Ministers came to a decision regarding the relations of provincial governors to inspectors of irrigation. It was then ruled that there should be two descriptions of contract. For those earthworks requiring the labour of more than 1000 men a day, for masonry works costing above 200*l.*, and for all works requiring the use of machinery, the contracts should be made at the Public Works Ministry. For all smaller works the contracts should be made at the governor's office, the contractors being selected jointly by the governor and the inspector of irrigation. Lists are kept of contractors whose offers will be accepted, but the Government is in no way pledged to accept the lowest or indeed any of the offers submitted. On the whole this system has worked well.

The canal clearances for the year are determined by an agricultural council, held in each Province about December. The flood or inundation canals, the drainage cuts, and the repairs of the embankments, can be done leisurely throughout these months, and there has been no difficulty in finding contractors to do them.

There remain the deep perennial canals, on which depend the cotton and sugar cane cultivation. These cannot be kept closed in spring or summer for more than three weeks or a month, and their bottoms, nearly 20 feet deep, below steep rugged banks, are always full of mud and slush. Their clearance has been our one contract difficulty, and hitherto we have not succeeded in solving it as we had hoped to do by dredging.

During 1885 two contracts were made. It was intended to do, through these contractors, the dredging of the Mahmoudieh and Ismailieh canals, which had been hitherto dredged by the direct action of Government, as well as that of the Rayah Behera, and, most important of all, those deep perennial canals to which I have just alluded. I am sorry to say neither of these contracts has been at all satisfactory. Neither the Irrigation officers nor the contractors fairly realised what difficulties these deep canals would prove. The dredgers that had been employed on the Mahmoudieh and Ismailieh canals were made over to the contractors, but they were useless for most of the others; and during 1886 it may be said that the contractors did very little dredging that had not been done as well by Government before. On the Rayah Behera, one of the few canals hitherto undredged, on which they tried to work, the failure of the old dredgers was conspicuous. The only new pattern that was tried to any extent was Priestman's Dredger, but it did not answer for the work required, and Mr. Forster remarks, 'the failure was due to unsuitable machinery, inferior supervision, and ignorance of the work in hand.'

The dredging contracts have been altogether badly drawn up—a circumstance I regret all the more that I am directly responsible for them.

The failure of the contractors on some of the deep perennial canals, forced us to employ corvée. It was decided to pay these men for their work, and the sum of 8076*l.* was thus spent altogether, the rate fixed being 2 piastres per cubic metre. This payment of corvée was altogether a new thing. Mr. Garstin describes as follows, the way it was worked:—

'Lists of men working were kept, village by village, and the amount done by each village as far as it could be estimated. When the work was done, an official on the part of the canals, accompanied by the wakil of the moûdirieh, went round to each village and distributed the money. Of course the fellaheen did not receive all the money put down for them, as a certain proportion must have found its way into the hands of the sheikhs, etc. Still, I believe that they got the greater portion of it, for this reason, that they took the keenest interest in it themselves, and constantly asked me about it, whereas since the distribution I have not heard a single complaint on the subject.'

I have not lost hope that we shall one day dredge all these canals. In the meantime, Mr. Garstin made a successful experiment last November. At that season there is no demand for irrigation, and everything is to be gained by closing the canals and allowing them to act as drains, to run off the surplus water from the fields saturated by the Nile flood. This season has never been used for canal clearances, chiefly because the agricultural councils have not then decided on their operations. But this last year, counting on the water level being lowered on all sides, by the closure of neighbouring canals Mr. Garstin gave out the clearance of five of his most difficult ones to contract. The deposit was about 1·25 metre deep in them. At the price of 4 to 5 piastres per cubic metre he succeeded in having them well cleared, the contractors pumping the beds dry before beginning work.

The contract system, with its active competition, has very much reduced rates. The rates per cubic metre for earthwork have been somewhat as follows in Lower Egypt:—

	piastres per cubic metre
Excavation of new canals	2 to 3
Clearance of canals, dry	1·5 to 2·5
Clearance of deep perennial canals, wet	4 to 6

In Upper Egypt the rates are somewhat lower. Captain Brown expresses special satisfaction at the good work done in the canal clearances and repairs to banks in the Province of Girgeh. The amount of earthwork was 1,378,551 cubic metres, costing 18,009*l.* or a mean rate of 1306 piastres."

Report for 1887.—" Mr. Garstin very truly remarks regarding the diminution of corvée labour:

'The Dakahlieh and Kalioubieh Provinces have made much less progress than Sharkieh in this way, and this is owing chiefly to the inefficiency of our staff in these two provinces, they being more or less of the ancient Egyptian type. In Sharkieh, on the contrary, we have a most intelligent man in charge, Ahmed effendi Said, who does his best to carry out our views.'

As stated in my last year's Report, I have little doubt that it is a good deal for want of intelligent supervision that the corvée maintains its immense numbers in the southern provinces. If we compare the corvée in the seven provinces of Lower Egypt with what it was in 1883, we see that, with an outlay this year of 126,067*l.*, with the

partial use of Barrage, and with the many improvements made within the canals since that date, the number employed on the corvée has been reduced from 106,616 to 27,512 men. Indeed, the numbers employed in Menoufieh in 1883 were nearly as many as the whole corvée of Lower Egypt in 1887.

In my Report for last year I alluded to the unsatisfactory outcome of the dredging contract in the three eastern provinces. I am glad to report a great improvement in 1887. After various experiments, the contractors have now got a very satisfactory form of dredger, the sand pump pattern, of which eight were employed. Mr. Garstin says of it:—

'The sand pump is undoubtedly the dredger for our perennial canals, whose beds are either fresh mud or sand deposit. It will not touch either mud or sand that has been deposited for several years and become hard. This only the bucket dredger or the Priestman can be used for. For the purpose of removing the annual deposit in our canals, however, I think it is the best form of dredger that can be found. It ought to do from 500 to 600 metres cube per diem, when properly supervised, and where the lift is not too great. For, of course, the greater the angle of the shoot, the greater the power required to force the stuff up through it.'

The dredging done in Behera was not much more satisfactory than it had been in 1886. That is to say, they succeeded perfectly well on the Mahmoudieh canal where there were no difficulties. From the Rayah Behera was removed 522,111 cubic metres of silt with six dredgers, a large quantity, but still much less than they should have done (one powerful dredger, No. 20, doing only 354 cubic metres per diem instead of 800 cubic metres, as might have been expected). In the smaller canals, where most of all we hoped to have good dredging done, no serious attempt even was made. The dredging in the eastern provinces has been, then, decidedly more satisfactory than in Behera.

The authors of the decree granting 250,000*l.* annually for the partial abolition of the corvée, have tied it down with restrictions which greatly detract from its value. It often happens that the introduction of a set of regulating sluices enables such a control to be exercised over the water in a canal that silt is no longer deposited, and the corvée no longer necessary to remove it. We have built works of this kind, of which the cost has not exceeded one year's silt clearance. But, as masonry works could not be done by the corvée, we dare not devote any of the 250,000*l.* to such works, and, instead of spending perhaps 500*l.* once for all, we are obliged to continue spending as much year after year in removing silt. A similar case frequently occurs in Upper Egypt. The long basin embankments are yearly washed away by the lap of the waves, and require remaking. Were we allowed to spend any of the 250,000*l.* in facing such banks with stone, the annual outlay of repairs would be saved. But this we cannot do, and so the yearly need of spending money.

The Corvée Relief Decree, in short, is on a par with most of the others which internationalism has devised for the welfare of Egypt.

Report for 1888.—"A further extension this year was made in corvée abolition, by the permission, accorded after much discussion, to the whole corvéable population of certain provinces to redeem themselves. It was an experiment, and was confined to the Provinces of Sharkieh, Menoufieh, Gharbieh, Giseh, Beni-Souef,

Minieh, and Assiout. The districts of Gafarieh, Zifta, and Mehallet el Roh in Gharbieh were exempted, and furnished corvée as usual. The ransom sum was fixed at 40 piastres per head generally throughout Lower Egypt, and for lands on the Ibrahimieh canal; 20 piastres in rice districts; 30 piastres in Upper Egypt generally. It was not until February that the measure was sanctioned, when corvée work was already begun and in progress. The difficulty at once arose as to who were the corvéable. The old census of Mohammed Ali was entirely out of date. The census of 1882 was not relied on. Some mûdirs like that of Beni-Souef, gave up in despair, and not a man in the province ransomed himself. In Minieh things were hardly better. While the active and intelligent Mûdir of Assiout found 59,000 men willing to pay ransom.

Among the peasant proprietors of Lower Egypt the corvée redemption has been very popular, and large numbers have readily paid. It is not so among the proprietors and owners of *Esbehs* (hamlets). Many of these are Europeans, and they look on themselves generally as a privileged class, who are entitled to all the State can give them, without rendering the slightest service in return. Mr. Willcocks calculates that while the numbers who paid ransom money per 100 acres were among the *fellahin* of Menoufieh at the rate of seventeen men and in Gharbieh of seven men, the holders of *Esbehs* paid in Menoufieh only for two men per 100 acres and in Gharbieh for two men for 500 acres. This glaring evil, we must hope, will be rectified ere very long.

The dredging done in the three eastern provinces was, on the whole, satisfactory. It amounted to 637,599 cubic metres against 802,795 done in 1887; but as 206,812 cubic metres dredged in 1887 were not paid for until 1888, they appear in financial accounts as belonging to the latter year. Of course it would be more satisfactory if such a large quantity were not required, but clearance done by dredging instead of hand labour is generally a gain.

In Behera, Mr. Foster reports that, for the first time, the dredging was done in a satisfactory manner. The volume dredged in the Rayah Behera and Khatatbeh canals was 563,745 cubic metres, against 522,111 in 1887."

Report for 1889.—"The year 1889 will ever be memorable owing to the abolition of the corvée, or forced labour, in December 1889; so that in 1890 there will be no forced labour throughout Egypt for the clearances of canals and repairs of banks. The corvée was abolished in December 1889, and for 400,000*l.* the Public Works Department undertook to do all earthwork repairs."

The quantity of work to be performed annually is determined as follows. Immediately after the flood the district engineers sound all the canals, and estimate the quantity of earthwork necessary in the perennial and flood canals separately, and in the banks and drains. These estimates are generally completed by the 15th December. They are submitted to Councils of Agriculture,* composed of the governors, the irrigation officers, and the village notables in each province. The councils meet in the first week of

* These Councils of Agriculture were instituted in 1871. The two Khedivial decrees which refer to them are dated 31st December, 1871, and 6th February, 1874, respectively.

January, discuss the estimates and pass them. The total expenditure of each canal is not allowed to exceed the sum allotted by Government.

Up to the present, the *corvée* on the earthwork maintenance have only been considered; we now come to the *protection of the Nile banks in flood.* The Khedivial decree of the 6th August, 1885, contains the regulations on this subject:—

KHEDIVIAL DECREE, OF THE 6TH AUGUST, 1885.

All those inhabitants who are bound to supply corvée by the decree of the 25th January, 1881, are equally bound to protect the banks of the Nile in flood.

On the 1st July, the Minister of Public Works will point out the points which ought to be protected and watched, and the number of men to be supplied.

On the 15th July, an assembly will meet in each province, presided over by the mûdir of the province, and having as members the village notables and assistant-engineers and executive engineer of the province. The President will communicate to the assembly the instructions received from the Ministry of Public Works relatively to the number of watchmen to be provided, and the assembly will divide them among the districts and villages.

Each village headman must forward to the mûdir of the province, before the 25th July, a nominal roll of all the men his village has to supply, divided into two lists.

The men in the first list will be at their posts on the 1st August, and those of the second list by the 1st September. The posts are not to be left by the watchmen, except on a special order of the Minister of Public Works.

The assembly of each province will select four notables, who, presided over by the executive engineer of the district, will form a commission for judging delays and contraventions on the part of the village headmen or the corvée.

Any head of a village or district, or any notable who neglects to supply the number of men required for his section, or who is absent from his post, or who quits it without permission, is within the twenty-four hours to be judged by the commission, and condemned to an imprisonment of not less than twenty days or over three months, and to a fine of not less than *2l.* or over *20l.* The man found guilty may be definitely dismissed from his post, if the commission considers it necessary, without prejudicing any damages which may be claimed from him, if damages have occurred owing to his absence or carelessness. If dismissed, he is to be immediately replaced by another notable.

If a corvée man fails to be present at his post, he shall be immediately judged by the commission, and condemned to an imprisonment of between twenty days and three months, and to a fine of from *1l.* to *10l.* In this case the village headman must immediately produce another man.

By a ministerial order of August 1887, the date for the first section of the corvée to turn out was changed from August 1st to August 15th. This was owing to representations made by the Ministry of Public Works that there was never any danger between the 1st and 15th of August; while this fortnight was especially valuable to the fellaheen as the time of putting in the Indian corn crop.

The Khedivial decree of the 25th January, 1886, laid down the punishments to be inflicted on the corvée who were absent from their work during *the canal clearances.*

The commissions appointed by the decree of the 6th August, 1885, *for Nile bank protection*, were called on to judge these cases which were made applicable to the Nile corvée.

"Any village headman or notable who neglects to furnish the number of men due for his section, or who is not present at his post to supervise his work, or who leaves his post without permission, is to be judged by the commission within the twenty-four hours, and condemned to an imprisonment of from ten to thirty days, or to a fine of from 2*l.* to 5*l.* He may not be dismissed from his post of village headman.

Any corvée man who fails to be present, or who deserts his post, is to be immediately judged by the commission, and condemned to a fine of ·5*l.* to 1*l.*, and to the performance of the work due from him. If he cannot pay the sum due from him, he must perform an amount of work represented by the fine."

These two last decrees are the outcome of the abolition of the kurbâsh. In the old kurbâsh days the corvée used to be flogged, now they are tried and punished in other ways.

Reading the above decrees, one might assume that these popular assemblies and popular tribunals would work well. When it is considered, however, that the men to be condemned to punishment are the village headmen and the fellaheen, while the real culprits are the large absentee proprietors and their tenants, it will readily be understood that the wrong men are generally punished. The assemblies would never dare to punish the tenants of a large proprietor or to report the delinquency of the proprietor himself. Many village headmen would send themselves to prison sooner.

Before leaving the subject of administration I should be doing a wrong to the Egyptian engineers with whom I have worked for so many years if I were not to put on record their very substantial grievances. Government servants are expected to live on their salaries. It is always assumed that their emoluments will suffice for all reasonable expenses. Now, what are the facts of the case? Young men of from sixteen to twenty enter the polytechnical school, and, after a four years' course, if successful, are appointed to the Public Works Department at salaries of from 4*l.* to 6*l.* per mensem. Their promotion is exceedingly slow, and I know really capable men who, after ten years' service, are only drawing 8*l.* per mensem. Government has all these years, asked these men to live up to their position, in the districts to which they have been appointed, on salaries which are not a half of what they have had to spend, and which the Government well knows that they have all along spent. These unfortunate men have been compelled, whether they have liked it or not, in almost every individual case, to take

bribes and rewards, and become a byeword and reproach in the country. Some, with naturally predatory instincts, have been let loose to prey on the country, and make their fortunes as quickly as they can, before they are discovered and replaced by others as bad as themselves. Others, with shame and humiliation, have been gradually forced into a life of petty theft and misappropriation at first, and afterwards of open fraud and dishonesty. The salaries of these same men when they climb to the higher appointments are sufficient to enable them to live upright lives, but the habits of dishonesty which they learn at the beginning of their career cling to them to the end. There are, of course, a few absolutely upright men whom no bribes can tempt, and occasionally, of course, men are found who have married into wealthy families or who have wealth of their own, but these constitute a very small minority. There is not a man in the country, from H.H. the Khedive and Lord Cromer to the smallest official in the Finance Department, who does not know that every word I say is true of very many of the departments, and especially of the Public Works Department.

Turning to a pamphlet written by Sir Elwin Palmer, financial adviser, published by the Egyptain Government, and entitled "Statistical Returns, 1881 to 1897," we come upon the following sentence:—

"The expenditure on public instruction has been increased by over 37 per cent., the number of schools has risen from 29 to 51, and the number of pupils from 5366 to 11,304."

When it is considered that 650 teachers are paid for teaching honesty and justice to 11,304 scholars, and that the great majority of these scholars who enter Government service will be compelled, one after the other, to unlearn all that they have learnt, and make a living from theft and dishonesty, the true reformer sees little to rejoice over. It would be better to close half the schools, and devote the savings to the provision of decent salaries for the scholars who have succeeded in entering Government service. No well paid European, who is enabled to live an honest and upright life, has any right to cast a stone at his unfortunate Egyptian colleague who does not enjoy equal advantages. The history of the East Indian Civil Service is full of instruction on this point. The old Bengal civilians of the eighteenth century who received nominal salaries, and who shook the pagoda tree to some purpose, were all Englishmen who were corrupted by the fact that their honest emoluments were notoriously insufficient. It was not till Lord Cornwallis introduced his wise reforms, and trebled and quadrupled the salaries, that the public services became what they are to-day. The Egyptian in his own country awaits a Lord Cornwallis. The reform will bring no medals and titles, but it will do more substantial good to the country than the possession of many Soudans.

The decrees and regulations which concern the Irrigation Department up

to July 1892, are to be found in Chapter III. of "La legislation en matière immobilière en Égypte," which is a collection of decrees, regulations and ministerial orders compiled by Mr. J. L. Gorst, and printed by the Egyptian Government in 1893.

Since that date no collection has been made, and the decrees and regulations have to be searched for in the ponderous volumes without an alphabetical index which represent the legislative efforts of the Government.

The following list gives the decrees in order as they are to be found in Mr. Gorst's book :—

Decree of the 12th April, 1890. The canal law; this was modified by the decree of the 22nd February, 1894.

Decree of the 12th November, 1890; cancelled by the decree of the 22nd February, 1894.

Decree of the 8th March, 1881. "Pumping engines"; followed by the Ministerial order of the 6th April, 1881.

Decree of the 12th April, 1890. Concerning the construction of canal heads or installation of water-lifting machines other than pumping engines.

Decree of the 3rd November, 1890. Agricultural roads.

Decree of the 25th January, 1881. Corvée.

Decree of the 6th August, 1885. Corvée.

Decree of the 9th September, 1887. Flood corvée, when the Cairo gauge passes 7·80 metres (24 pics).

Decree of 28th January, 1892. Abolition of earthwork maintenance corvée.

Decree of the 16th January, 1891. Destruction of locusts.

The decree of the 10th December, 1894, orders that the sums produced by the tolls on canal ferries are to be devoted to the construction of bridges to supersede the ferries.

Previous to the 12th of April, 1890, there was no canal law. On that date was passed the first canal law, which was modified by the decree of the 22nd February, 1894. The law of the 22nd February, 1894, has the following forty-three articles, of which the headings are here given.

To show how necessary a law of some kind had become, I shall give two instances out of many which came under my own notice. At two regulators on irrigation canals, Greek tradesmen had built shops and practically taken possession of two important works. As they had roofs over their heads, they were protected by the capitulations, and the Government had to submit to the indignity of not being able to utilise its own works. As the law was powerless, the inspector of irrigation was only able to force them to quit by building walls round them and starving them into surrender. In another instance, a small colony of Greek settlers had filled up a village watercourse about 2 kilometres long and 4 metres wide, had sown it with cotton, and was on the eve of forcing the helpless villagers to sell their land,

now become valueless, for a nominal sum. Fortunately, the British occupation had caused a new day to dawn upon the country, and the villagers appealed to the English inspector. He had the cotton cut down, and the canal re-dug, while a number of Greeks, with old revolvers and firearms, threatened to shoot the contractor if he continued his work, and indeed if an Englishman had not been present they would not have hesitated to carry out their threats. These facts will give an idea of the straits into which the capitulations had driven Egyptian irrigation, and from which nothing but a strong executive and just legislation could have rescued it.

THE EGYPTIAN CANAL ACT OF FEBRUARY 1894.

ART. 1. Canals and public embankments.
" 2. Private water-courses.
" 3. Drains.
" 4. Works for protection against inundation.
" 5. Powers of inspectors of irrigation and of chief engineers.
" 6. Servitudes on land.
" 7. Stoppage of pumps, or closure of canals.
" 8. Construction of perennial water-courses.
" 9. Passage of water across another's land, in absence of other means of irrigation.
" 10. Insufficient volume of a water-course.
" 11. Change of water-courses.
" 12. Construction of sluices, or erection of water-lifting machinery on the canals.
" 13. The suppression of a water-course to prevent damage.
" 14. Diminution in the size of the culvert of a water sluice, or alteration of its floor level.
" 15. Construction of a drain passing through another's lands.
" 16. Repairs of a water-course to prevent damage.
" 17. Shifting the position of a water-course which does not meet the requirement of irrigation.
" 18. Of the difficulties that may arise regarding the repairs of a water-course.
" 19. Destruction of embankments, or filling in of water-courses or drains.
" 20. Removal of trees planted on the banks and slopes of canals.
" 21. Permission to cultivate on the banks or in the bed of a canal.
" 22. Transformation of a cultivated embankment into a public road.
" 23. Construction or repair of a culvert in the bank of the Nile or of a canal.
" 24. Works of defence against inundation.
" 25. Diversion of the course of the Nile.
" 26. Loading and unloading of boats.
" 27. The valuation commission.
" 28. Boat owners have no claim against Government.
" 29. Wreck or sinking of boats.
" 30. Establishments of ferries on canals.

ART. 31. Right of boats to lade or unlade on the banks of the Nile or canals.
„ 32 to 37. Contraventions.
„ 38. The composition of the procedure commission for the trial of offenders, and the special committee for hearing appeals.
„ 39. The Ministry of the Interior to make special rules for procedure to be followed.
„ 40. Responsibility of village headmen and urban authorities.
„ 41. Method of recovering fines.
„ 42. All previous laws are cancelled.
„ 43. The Ministers of Public Works, Interior, Finance and Justice are charged with the execution of the decree.

The pumping engines on the Nile and the canals are subject to a special law:—

DECREE AND REGULATION FOR WATER-RAISING MACHINES, 8TH MARCH, 1881.

ARTICLE I. It is, and remains forbidden to establish engines to lift water for irrigation or drainage, whether fixed or movable, whether their motive power be steam, water power, or wind, without having previously obtained an authorisation of the Ministry or of the Public Works services. This authorisation does not give to the person benefiting by the use of the engine any right of property, *in any limit whatever*, in the public or private State Lands occupied or traversed by the pipes, conduits or aqueducts of the sluice and place of intake.

The Government does not concern itself in any relations between the person benefiting from the use of the engine, and other parties; it lays on the licensee the responsibility for all hurtful acts or other injuries caused by erection of the engine or otherwise.

II. The establishment of stationary water-lifting engines will not be allowed except on the banks of the Nile: but the Ministry of Public Works may in exceptional cases authorise their erection on certain canals.

The Ministry alone is the judge of the suitability of the erection, and reserves to itself the free liberty to impose (in considering the special case) any obligations and conditions it considers necessary.

III. Every water-lifting engine, whether stationary or movable, is under the common obligation to leave completely free the circulation on the banks and canals; to respect all the "servitudes" in force; to hinder in no way the necessary works for the maintenance of these banks and canals, and for the defence of the country against inundation.

IV. The failure to comply with every or any condition or obligation imposed by the license to establish a water-lifting engine, will give Government the full right to cancel the license, without in any way waiving rights which the Government possesses and reserves to itself of carrying out the necessary repairs and reimbursing to itself the cost of the repairs.

V. An engine licensed for a given place cannot be displaced without the issue of a new license; no new license fees will be payable.

VI. The Government reserves to itself the right by reason of public utility

(construction of public works; danger to the banks, masonry works, etc.), to displace any licensed engine.

VII. The license to erect an engine (whether stationary or movable) to raise water, does not grant the right for the licensee to set up a machine to take water from the Nile or a canal. It does not lay the Government under any obligation to maintain a continuous supply of water to the engine. For the passage of water raised by the engine the licensee must arrange with his partners or other parties whose lands it is necessary to cross, without any intervention of any sort on the part of Government. For the passage of water across the waste lands or other lands of Government, the licensee must obtain a special permission.

It is forbidden to make watercourses for the passage of the water raised by the engines, either along the banks of the Nile or the canals, or along the berms or bank-slopes of the Nile or canals.

VIII. The watercourses or conduits to take the water to the fields will be established in such a manner as will not impede either the traffic on the banks, whether of men or beasts, or the circulation of drainage or irrigation water. The licensee alone shall remain responsible for all the rights of other parties for the passage of traffic or drainage or irrigation water. The Government will decide on all the works that the licensee must construct, necessary for the passage of his water under the road and banks, and above and below the canals crossed by the watercourse.

IX. By reason of public utility, in case of an exceptionally low summer supply, or when the discharge of a canal becomes notoriously insufficient for the demands of the cultivation on it, the Public Works services can, by a measure applicable to a whole canal, or one reach only of a canal, order a temporary stoppage of engines for raising water, or may order a reduction in their speed and discharge, in taking into account, if necessary, the relative importance of the machines and of the lands they irrigate. In these and similar cases the Government does not incur any responsibility for damages caused to crops.

X. In suspension of Article VII., the Ministry of Public Works can, as an exception, authorise the use of a public Nílí canal (a Nílí canal is that which flows only during the Nile flood) to conduct the water raised by the engine to the lands it is destined to irrigate, and this authorisation is granted under the following reserves:—

(1) The permission is only granted for one summer season, which ends when the Nile water enters the canal by natural flow.

(2) The permission is only granted if the proprietors of the lands irrigated naturally by the canal have given their unanimous consent to this permission.

(3) If it has been found necessary to make dams in the Nílí canal to hold up the water, the dams must be of earth, and must be cleared away by the proprietor of the engine before the Nile water flows naturally into the canal. In the case of his not doing so the Government will remove the dams at the cost, risk and peril of the engine proprietor before the Nile water rises naturally into the canal.

(4) Finally the proprietor of the machine is alone responsible to other parties for all damages done by breaches in the banks; percolation, and delay in the raising of the banks during the time of supply of water from the engine.

XI. Every person who, contrary to the rules in force previous to the present

decree, shall have erected a stationary or movable engine without license, must before the 31st August, 1881, apply for a license under the conditions imposed by the present decree and its regulations. All persons possessing a license issued before the coming into force of the present decree must, before the same date, provide himself with a new license under the same condition, and he shall not be liable to pay new license fees.

XII. After the 31st August, 1881, every engine established in opposition to the conditions of Article II. above noted, shall be stopped from working.

XIII. The proprietors of engines are responsible for the damages or accidents occasioned by their engines; the Government, however, reserves to itself the right, in the public interest, of inspection of these engines without relieving the proprietors of the responsibility under which they lie.

XIV. Regulations for putting in force this decree, and to the observance of which those interested are bound, shall be framed by the Ministry of Public Works.

XV. Our Minister of Public Works is charged with the execution of the present decree.

MINISTERIAL ORDER.

Regulations applicable to Water-raising Engines.

ARTICLE I. Every application for the licensing of a movable engine for raising water shall be made on stamped paper, and addressed to the Mûdiriyah, or the local Governor's office, in the circle in which it is desired to erect the engine.

The application must contain the following information:—

(1) The class of engine and its pump, with details of the horse-power and principal dimensions.

(2) The site of erection, with a plan.

(3) The work which the engine is required to do: irrigation or drainage.

(4) The names in full, professions, nationalities, residences of the proprietors of the land it is proposed to irrigate or drain.

(5) The period for which the license is required.

II. The application for license, registered in a special register in the Mûdiriyah or local Governor's office, will be numbered in sequence after payment of a fixed fee of 100 piastres* to cover cost of examination. It is then transmitted for examination to the engineer-in-chief of the circle in which the the Mûdiriyah or local Governor's office exists.

III. The engineer-in-chief of the circle accepts the license if he thinks fit, and signs the license, which should contain:—

(1) The agreement of the engine proprietor to conform to the present regulations and to all future legislative enactments or future regulations.

(2) The exact description of the site of the engine, with a sketch illustrating it, if he thinks fit.

(3) The special conditions of the engine, notably those relative to the culvert under the bank of the canal at the head sluice; its mode of closure, etc.

The license not being necessary for the public benefit, it is to be well understood that private persons are free to demand compensation from the proprietor of the

* 1·00*l.*

engine for any rights, etc., they enjoy in the lands where the engine is to be erected, or to oppose its erection in a legal way.

IV. The license sent by the engineer of the circle to the Mûdiriyah or the local Governor's office, is to be signed by the engineer of the circle (Inspector of Irrigation) and sent by the Mûdir or Governor to the engine proprietor, in order to obtain his signature to a duplicate copy of the license, which is transcribed on the register itself of applications; and on payment of a fee of 50 piastres * per horse-power. This tax, however, shall never be lower than 500 piastres, or 5·*ol.*

V. All applications for a license for the erection of a stationary engine must be addressed on a stamped paper to the Ministry of Public Works, which grants directly the licenses, if it thinks it. The application shall always be accompanied by the whole site of the proposed erection of the engine and its sluice, and in default of a plan of the machinery, a detailed description of the machinery shall be sent in.

VI. The licenses for the erection of a stationary engine are taxed on the same scale of fees for examination and license as for movable engines.

These fees are payable at the Treasury of the Public Works Ministry.

VII. On no pretext whatever can the applicant for a license put in hand the works necessary for the erection of plant or engine before he receives the license.

VIII. No engine for raising water may be established on the head sluice, regulators, weirs, or other masonry works of public interest, or near these works, without the distance being fixed in each case by the Ministry of Public Works.

IX. The license indicated in Article 5 of the Decree of the 8th March, 1881, shall be given by the engineer-in-chief of the circle, who will notify to the Mûdiriyah or the local Governor's office the site which he has authorised.

X. The displacement of engines indicated by Article 6 of the Decree of the 8th March, 1881, cannot be ordered, except by the Ministry of Public Works. The displacement shall be carried out at the cost of the proprietor.

XI. All regulations and rules heretofore in force are cancelled, as far as concerns the present regulations.

The following is a translation of the decree of the 12th April, 1890 :—

DECREE OF 12TH APRIL, 1890.

The Construction of Watercourse Heads or the Erection of Water-lifting Machines on the Canals.

If a proprietor wishes to construct a watercourse head or erect a sakieh or water-lifting machine on a canal bank in order to irrigate his land, he must present his demand to the Governor of the province, who will send it to the Inspector of Irrigation with his opinion and remarks, if he has any. The latter will forward it to the chief engineer of the province, who, if he approves of the proprietor's demand, will give the necessary permit in the case of a sakieh, or submit the question for the approbation of the Inspector of Irrigation if it refers to a watercourse head. A copy of the permit must in any case be transmitted to the Governor of the province, accompanied by a declaration that the discharge of the canal allows of the construction of the watercourse or the erection of the

* ·50*l.*

sakieh without inconvenience to the proprietors of other watercourses situated downstream of it.

The chief engineer shall first exact from the petitioner an engagement to make at his own expense all the works necessary for regulating the discharge of the water in the watercourse, or for maintaining the banks of the canal in proper condition.

The chief engineer has to fix the site of the watercourse head or the sakieh. The procedure for erecting stationary or portable engines, worked by steam, wind, or water, is regulated by the Act of the 8th March, 1881.

In no case can sakiehs or water-wheels be erected without permits previously obtained from the Government. This permit, if it is granted, shall be given free.

Previous to the passing of the canal law, irrigation matters were referred to a few articles of the codes applicable to the native and mixed tribunals. The following are from the native tribunals codes: those in the mixed tribunal codes are practically the same ('L'irrigation en Égypte,' par J. Barois).

1. The court of summary justice decides finally all cases of less than 10*l.*, while all cases exceeding this sum, however great the urgency may be, are subject to appeal, . . . for damage to fields, fruit and produce, whether caused by men or animals.—[*Art.* 26, *Code de Procedure.*]

2. The right to use the water of the canals constructed by the State is proportional to the lands to be irrigated, except in so far as is provided for in the special laws, decrees, and rules.—[*Art.* 31. *Code Civil.*]

3. Any one who has constructed a canal has the sole right to use this canal, or to sell it.—[*Art.* 32, *Code Civil.*]

4. Every one is held liable to provide on his estate a passage for the water necessary for the lands furthest removed from the head of the watercourse. The courts will first decide the amount of indemnity due; and in case of dispute the works necessary to be carried out, so that the water may be conducted through the estate with the least possible damage.

5. The proprietor who irrigates his lands by means of machinery or of canals cannot compel the lower lands to receive the water from his estate.—[*Art.* 33, *Code Civil.*]

6. The public domains are unchangeable, and cannot be seized or alienated. The Government alone can dispose of them by law and decree. They comprise . . . the rivers navigable by boats or rafts, and the canals of which the maintenance is at the charge of the State.—[*Art.* 9, *Code Civil.*]

7. Form equally a part of the public domains the "servitudes" of watercourses, of public works, and more generally all the active "servitudes" of common right attached to the property of the public domains, or which can result from the laws or decrees passed in the public interest.—[*Art.* 10. *Code Civil.*]

8. He who, by breaching the banks, or in any other manner, shall have caused mechanically an inundation, will be, according to the gravity of the offence, condemned to hard labour for a certain time or for life.—[*Art.* 334, *Code Penal.*]

9. Whoever will have voluntarily destroyed, or overthrown, or damaged, by any means whatever, entirely or in part, bridges, aqueducts, banks, . . . belonging

to another, . . . will be condemned to an imprisonment of from three months to two years, and to a fine equal to a quarter of the cost of restitution.—[*Art.* 336, *Code Penal.*]

10. Will be punished by a fine of from ·05*l.* to ·25*l.*, those who will not have conformed to an administrative order, when this order shall not have determined beforehand the punishments to be inflicted for infractions.—[*Art.* 341, *Code Penal.*]

11. Will be punished by a fine of from ·5*l.* to 1·0*l.*, and to six days' imprisonment, those who will have injured . . . the public roads . . . or other places of utility, or those who will have encroached on them.—[*Art.* 347, *Code Penal.*]

CHAPTER XIV.

RESERVOIRS.

Basin and perennial irrigation compared—History of the reservoir question—Reports—Agricultural side of the question—Water needed for Lower and Upper Egypt—Methods of obtaining this water—Solid insubmergible dams—Proposed dam at Assuân—Sir John Rogers' Report—The Report of the Technical Commission—Sir William Garstin's Report—Description of the dam under construction at Assuân—Size of reservoir—Sluice gates—Lock channel—Cost of work—Cost of water storage—Wady Rayan Reservoir—Inlet and outlet canal—Method of filling and emptying—Cost of work—Quantity of water stored—Basin reservoirs—Description and method of employing—Quantity of water stored, and cost—Colonel Ross' criticism—Comparison of different systems of water storage—The Assiout Barrage and the Ibrahimia Canal head—The Samanud Barrage—Sources of the Blue and White Nile as reservoirs—River training in the Sadd region of the White Nile.

THE most casual study of the preceding chapters will have made one acquainted with the fact that two systems of irrigation are practised side by side in Egypt. The ancient or basin system is confined to a little more than three-fourths of Upper Egypt, and the modern or perennial system is employed on the remaining one-fourth of Upper Egypt and the whole of Lower Egypt. The perennial system applied to suitable lands is more profitable than the basin system, but depends on the summer supply of the Nile, which is both limited and irregular in quantity. Basin irrigation depends on the flood, which is practically unlimited and very fairly regular in quantity. To reclaim waste lands, improve deteriorated lands, and renew old and fatigued lands, the basin system which has come down from the Pharaohs is the best. To develop good lands and make them yield their maximum when skilfully handled, the perennial system has undoubtedly the advantage.

It would have been well for the country if, in all schemes for its development, the two systems had always gone hand in hand. Unfortunately for Egypt in the first half of this century, when perennial irrigation was introduced, the relative advantages of the two systems were not understood, and every effort was made to convert basin irrigation into perennial, so as to increase the areas under cotton and sugar. No notice was taken of the fact that many of the tracts so treated were totally unfitted for perennial irrigation. Mehemet Ali was one of those characters who possessed the power of stamping his individuality on everything he under-

took, and cutting such deep grooves for his ideas that his successors have found it difficult to get out of them even when the ideas have been wrong. It was thus on the question of the wholesale introduction of perennial irrigation.

In Mehemet Ali's time, as has been already stated, the great preoccupation of the Government was the pressing on of the cultivation of cotton, and as this crop needed perennial irrigation, the securing of an abundant supply of water all the year round was the problem of the day.

The fame of the ancient Lake Mœris had made a profound impression on the mind of the viceroy, and he urged on his Chief Engineer, Linant Pasha,* the necessity of undertaking similar works. Linant Pasha first set himself to discover the site of the ancient lake, and then estimated roughly the cost of reconstructing it, but considered the cost prohibitive.† He also recommended Gebel Silsila as a suitable site for a weir and canal head.‡ The failure of the Barrage discouraged the Government from undertaking new works and the question dropped. In 1880 Count de la Motte,§ a Frenchman, took up the question of reservoirs and proposed a dam at Gebel Silsila and a reservoir to the south of it; the works were to have cost 4,000,000*l.* exclusive of compensation, and the reservoir was to have contained 7,000,000,000 cubic metres of water. As a counter project to this, Mr. Cope Whitehouse,‖ an American gentleman, in 1882 suggested utilising the Wady Rayan, a depression in the desert that had already been mentioned by Linant Pasha in his book ¶ and located by him on his hydrological map. Financial difficulties and the supposed failure of the Barrage prevented the Egyptain Government at that time from seriously considering the question of reservoirs for increasing the discharge of the Nile, as it had insufficient means of utilising the supply then existing. The subsequent success of the Barrage gave new life to the question of reservoirs, and at the request of Sir Colin Scott-Moncrieff, the Government deputed Colonel Western, Director-General of Works, to give shape to the suggestions made by Mr. Cope Whitehouse, to make plans of the Wady Rayan and the deserts between it and the Nile, to find out the capacity of the reservoir and see if it could be utilised. Liernur Bey and a staff of engineers were placed under his direction, and they prepared the contoured map of the Wady Rayan and surrounding deserts. Colonel Western's

* 'Memoires sur les travaux publics en Egypte,' by Linant de Bellefonds, Paris, 1873, pages 418 and 419.

† Op. Cit., pages 88 and 420. ‡ Op. Cit., pages 397 and 398.

§ 'Le Nil,' by the *Société d'études du Nil.* Date on the plan of the Semne Cataract, by Mr. Cotterill.

‖ Bulletin of the American Geographical Society. 1882, No. 2, pages 22 and 24.

¶ 'Memoires sur les travaux publics en Egypte,' by Linant de Bellefonds, Paris, 1873, pages 53 and 57.

report, plans and estimates were printed by Government.* Partly owing to financial considerations, but still more to the differences of opinion among the officers of the Irrigation Department as to the feasibility of carrying out the project, the question was for the time shelved.

Meantime the other project of Count de la Motte for reservoirs in Nubia was being studied by me for the Egyptian Government, and, on its being unfavourably reported on owing to the mistakes in levels, in 1889 Mr. Prompt, a member of the Egyptian Railway Board, suggested utilising the trough of the Nile itself for a reservoir in the absence of the low plains which did not exist. As by this time the Barrage repairs were practically completed, the Government, again at the request of Sir Colin Scott-Moncrieff, decided to study the question of the reservoirs anew, and did me the honour of appointing me Director-General of the study, with Messrs. Hewat, Roux, Clifton, Stent, Abder Rahman Rushdy, Abdalla Hassib, Mohamed Saber and Mohamed Balig as Assistants.

Fortunately for the country, at the same time that the reservoir studies were undertaken, Colonel Ross was entrusted with the work of remodelling and improving the basins and basin canals south of Assiout, which had failed in the extremely low flood of 1888, owing to long neglect. He soon proved what was so earnestly insisted on in the first edition of this work, that basin irrigation had a great future before it just as perennial irrigation had. The one needed the skilful and plentiful use of flood water just as the other needed reservoirs. At this stage of the studies I pressed on Sir Colin Moncrieff the necessity of permitting me to make a comparative study of the different systems in every part of Egypt, so that we might decide where perennial irrigation was needed and where the basin system was better. I contested that this study was an essential part of the reservoir project, but I was overruled by public opinion, which was in a hurry to see a start made with the reservoirs. My first report was published in 1891, the next in 1894, and the last in 1895. On the agricultural side of the question the information the reports contained was necessarily the best which was at my disposal at the time of writing.

The reservoir report of 1895 was barely completed when I was appointed Director-General of the land tax adjustment operations, with a strong staff of land experts to find the land valuation of the whole of Egypt. The inquiry lasted two years, and I then had the opportunity of making the study which would have been so opportune in 1890.

On pages 106, 162 and 176 the existing areas under basin and perennial irrigation have been classified according to the value of their gross yield. Taking the renting value of Upper Egypt as 54 per cent. of the gross yield, and that of Lower Egypt at 58 per cent., we arrive at the following figures:—

* 'Notes on the Wady Rayan,' by Liernur Bey, Col. Western and Sir Colin Scott-Moncrieff, Cairo, 1888.

Basin tracts in Upper Egypt.

40,000 acres	at £8·12	(mean renting value).		
140,000 ,,	at 6·48	,,	,,	
250,000 ,,	at 4·32	,,	,,	
1,000,000 ,,	at 3·24	,,	,,	
180,000 ,,	at 1·62	,,	,,	
122,000 ,,	at ·81	,,	,,	
1,732,000				

Perennial tracts in Upper Egypt.

150,000 acres	at £8·12	(mean renting value).	
46,000 * ,,	at 6·48	,,	,,
100,000 ,,	at 4·32	,,	,,
110,000 ,,	at 2·70	,,	,,
112,000 ,,	at 1·62	,,	,,
69,000 ,,	at ·81	,,	,,
587,000			

Perennial tracts in Lower Egyyt.

1,100,000 acres	at £6·96	(mean renting value).	
700,000 ,,	at 4·64	,,	,,
500,000 ,,	at 2·90	,,	,,
330,000 ,,	at 1·74	,,	,,
800,000 ,,	at ·87	,,	,,
500,000 ,,	at 0	waste land.	
3,930,000			

Or, *For the whole of Egypt.*

4,130,000	190,000 acres	at £8	(mean renting value).	
	1,280,000 ,,	at 7	,,	,,
	1,050,000 ,,	at 4·5	,,	,,
	1,000,000 ,,	at 3·25	,,	,,
	610,000 ,,	at 3·00	,,	,,
2,120,000	630,000 ,,	at 1·70	,,	,,
	990,000 ,,	at ·85	,,	,,
	500,000 ,,	at 0	waste land.	
	6,250,000			

The first fact which strikes one is that of this area of 6,250,000 acres 4,130,000 acres produce a rental of over 20,000,000*l.*, and 2,120,000 acres produce a rental of under 2,000,000*l.* Practically one-third of Egypt is totally undeveloped. Nearly the whole of this undeveloped land lies in the perennially irrigated tracts. The summer supply of the Nile, on which perennial irrigation depends, is not sufficient for the needs of this irrigation. By referring to pages 142 and 143, it will be seen that the discharges actually required for the *existing perennially irrigated tracts* of Upper and

* 6000 acres on Lower Egypt canals.

Lower Egypt are 70 and 430 cubic metres per second respectively, or 500 cubic metres per second in all. No count is here taken of the 500,000 acres of waste land in the Delta. If these discharges could be permanently ensured, land reclamation would have a new lease of life. Without this insurance the ever-present fears of drought will doom all efforts to failure. Turning to the table on page 143, which gives the discharges between 1881 and 1898, it will be found that

In 1882	the available	discharge	in summer was	280	cubic metres	per second.
1885	"	"	"	350	"	"
1889	"	"	"	230	"	"
1890	"	"	"	280	"	"
1891	"	"	"	400	"	"
1892	"	"	"	330	"	"

while in six other years the discharge was under 450 cubic metres per second.

The critical period is between May 1 and July 15, or for a period of seventy-five days, during the whole of which period a minimum discharge of 500 cubic metres per second should be ensured for the tracts already under perennial irrigation. If we take 250 cubic metres per second as the minimum available supply in the Nile during the 75 critical days, reservoirs should be called on to supply the difference, or 250 cubic metres per second. This means 1,600,000,000 cubic metres at the heads of the canals, or 2,000,000,000 cubic metres at the reservoirs, if the reservoirs are situated anywhere in Egypt.

To ensure the irrigation of the existing perennially irrigated tracts, and to give the money invested in reclamation works a chance of paying appreciable returns, this quantity of 2,000,000,000 *cubic metres should be considered a first charge on the reservoirs.* When this has been met then other works might be undertaken. In my opinion the idea of turning to the basins and applying reservoir water to the work of changing them into perennially irrigated tracts, while there are some 2,000,000 acres of land professedly under perennial irrigation but which at present have only a nominal value for want of an assured summer supply, is neither statesmanlike nor is it fair to the proprietors of the lands. The Irrigation Department should never rest satisfied until it has reclaimed the 2,000,000 acres of waste land in Egypt, and brought them to the same state of prosperity as they enjoyed during the Roman occupation of the country, when the ancient Pharaonic system of irrigation was in vogue.

It has been stated that 2,000,000 cubic metres of water are needed at the reservoirs to supply the wants of the existing perennially irrigated tracts. If the 500,000 acres of waste land in the Delta are to be reclaimed by perennial irrigation, they will need another 1,000,000,000 of cubic metres; while the 1,730,000 acres of basin land, if they are to be converted into perennially irrigated tracts, will need another 3,000,000,000.

This means 2,000,000,000 cubic metres for the existing perennially irrigated tracts, and 4,000,000,000 for the rest of Egypt, or 6,000,000,000 cubic metres in all.

The quantity of water seems excessive, but if the whole of Egypt is ever to be brought under profitable perennial irrigation, every cubic metre of this water will have to be provided. The true solution of the problem will be found in accepting the fact that only 4,130,000 acres can be profitably provided with perennial irrigation, and the remaining 2,120,000 acres are better unde basinr irrigation. It will be thirty years before the country will accept the truth of this saying.

If it were accepted that perennial irrigation were needed for only 4,130,000 acres, the water to be stored would fall to 4,000,000,000. This would represent 3,200,000,000 in the canals or 500 cubic metres per second during the seventy-five critical days.

Having calculated the quantity of water required for the perennial irrigation of Egypt, it remains to describe the methods of storing it. I quote from my Report of 1894:—

"We have now to consider the methods of ensuring the required supply of water to Egypt. Water may be stored in reservoirs in the valley of the Nile, in depressions in the deserts outside of the Nile valley, and in waste lands in the Delta.

Reservoirs in the Nile valley can be formed by constructing, at places where a suitable rocky bed is available, solid sumergible dams over whose crests the river in flood may discharge itself; or by constructing solid insubmergible dams and turning the Nile over waste weirs; or thirdly by building insubmergible dams provided with numerous under sluices capable of discharging the flood waters without any material interference.

Of solid submergible dams there is a considerable number in existence, but they have been generally built on inconsiderable streams. The Turloch dam in California and the Betwa dam in India have, however, been constructed on considerable rivers. The Turloch dam is 102 metres long and has a maximum height of 40 metres, with a maxmum depth of water over the crest of 4·5 metres.* The floods there must be rare and of short duration or the work could not stand. The Betwa dam is 1080 metres long and has a maximum height of 18 metres, with a maximum depth of water over the crest of 5 metres.† At the Betwa dam the cross section is so designed that the water flowing over the dam in flood cannot strike the downstream face, while at Turloch the flood waters flow down the face of the dam. On a river like the Nile, whose floods are considerable and of long duration, I think that a solid submerged dam 12 metres in height is the highest which could be built with security. The downstream face of such a dam could be made vertical or nearly so, and there would consequently be no action on it.

Of solid insubmergible dams with waste weirs there are very many examples in existence. The earliest works of this kind are in Spain, while in France, dams were

* 'Manual of Irrigation Engineering,' Wilson, New York, 1893, page 295.

† Public Works Department, N.W.P. India, Proceedings, July 1888.

first built on the modern scientific principle of width proportional to pressure. The whole question of dams of this type has been exhaustively treated by the Italian Engineers Zoppi and Torricelli,* while Appendix I. contains an epitome which I have made in English of their valuable works. Such dams are built at times of considerable height; e.g. the new Puentes dam in Spain is 72 metres above its base, while 50 metres is quite an ordinary height nowadays.

All solid dams are provided with small scouring sluices for the purpose of scouring out the mud which has deposited in the reservoirs owing to the ponding up of the rivers in flood. These sluices have, however, been a conspicuous failure on all muddy streams, except where the reservoir is very narrow and has its bed on a very steep slope. At the 1889 Paris International Congress for the utilisation of rivers, Mr. Llaurado, a Spanish engineer, stated that in a few years the Puentes reservoir had silted up to a vertical height of 14 metres, while the Nijar reservoir had silted up to the very top of the dam.† Two reservoirs in Algeria have been conspicuous failures owing to the same cause.‡ Indian irrigation literature teems with this subject. When we have to do with a river like the Nile, which has a slope of $\frac{1}{13000}$, which occasionally runs liquid mud in August, and is heavily charged with matter in September and October, we may safely predict that any works which materially interfered with the flow of the water in flood, would immediately cause a heavy deposit of silt and steady obliteration of the reservoir. We may have an idea of the amount of silt the Nile is capable of depositing if we consider that, during an average flood at Assuân, the Nile carries in suspension. §

In August	11·71 cubic metres of solids per second
September . . .	5·33 „ „ „ „ „ „
October . . .	2·75 „ „ „ „ „ „
November . . .	1·42 „ „ „ „ „ „

or say 55,000,000 cubic metres in four months. The reservoir would be decreased by this amount per annum, while the soil of Egypt deprived of this rich mould would become poor indeed. We may look at the question from another point of view. Judging from observations on the Assuân and Cairo gauges, we estimate that the soil has risen 0·12 metre per 100 years on 5,000,000 acres, or 24,000,000 cubic metres per annum. I also estimate that 36,000,000 cubic metres of mud reach the sea per annum, so that the mean discharge of solids per annum at Assuân may be taken at 60,000,000 cubic metres. These quantities are so serious, whichever way we look at them, that they exclude any hope of constructing solid dams of the ordinary type in the valley of the Nile downstream of the Atbara junction.

It now remains to consider the third class of reservoir dams, namely insubmergible dams with numerous under-sluices capable of discharging the flood waters without much more interference than the sill of an ordinary rapid on the Nile. With such dams the muddy flood waters will be able to pass on without parting with their silt, and when the comparatively clear winter supply has commenced to flow, the sluices

* 'Laghi Artificiali dell'Algeria, della Francia e del Belgio,' Roma 1886. 'Laghi artificiali e irrigationi della Spagna,' Florence, 1888.

† Congrès de l'utilisation des eaux fluviales, Paris, 1889, pages 7 and 8.

‡ 'Les Irrigations,' A. Ronna, Paris 1888, vol. i. page 521.

§ Proceedings of the Institution of Civil Engineers, London, vol. 90, page 244.

in the dam will be gradually closed and the excess water in the river stored for use in summer. When I wrote my first report on dams on the 1st May, 1891,* I thought that the idea was a novel one; since then, however, I have heard of the Bhatgarh reservoir dam on the Nira river in Bombay, and have before me the report on the work.† On page 16 of that report, there is a quotation from a letter of Colonel Fife, written in 1889, in which he recommends that the dam be constructed with numerous under-sluices, so that floods with their silt might be passed through it and thus obviate the silt difficulty. Mr. Whiting, the engineer in charge of the design, designed and built the dam with 15 sluices of $2\cdot4 \times 1\cdot2$ metres, spaced 5 metres apart. The sills of the sluices are from 5 to 11 metres above the foundation level of the dam, and 26 metres below highest flood level or high-water level of the reservoir, which is one and the same. For high floods there are two waste weirs with a joint waterway of 243 metres $\times\ 2\cdot5$ metres, with their sills $2\cdot5$ metres below high-flood level. The 15 under-sluices are regulated by means of cast-iron gates worked by screw gearing. After the first heavy floods in July, the river is discharged through the sluices with a head of from 1 metre to $4\cdot5$ metres, and occasionally there has been a head of 13 metres on the sills of the sluices. It is estimated that the maximum velocity through the under-sluices may rise to 18 metres per second,‡ which seems very excessive. The whole design is extraordinarily bold and hardy. The section of the dam has not been increased at the under-sluices. The ashlar work is 38 centimetres thick.

For the Nile I propose a waterway of 2000 square metres in the under-sluices and no waste weirs of any kind. The undersluices will discharge the whole flood and ensure the reservoir from being obliterated. The mean maximum flood of the Nile at Assuân is 10,000 cubic metres per second, and this will be discharged with a mean velocity of 5 metres per second and head of 2 metres ($v = \cdot8 \sqrt{2gh}$). The August flood of 8000 cubic metres per second will be discharged with a velocity of $4\cdot25$ metres approximately, and head of $1\cdot5$ metre. An extraordinary flood of 14,000 cubic metres per second, which comes two or three times in 20 years and lasts a few days, will be discharged with a velocity of 7 metres per second and head of $4\cdot25$ metres. In the above calculations the velocities are taken at the section through the sills, while there is a drop of 50 centimetres in the floor immediately below the sills. The muddy flood discharge will be scarcely interfered with, and that is the principal point as far as the silting up of the reservoir is concerned. The granite ashlar under-sluices will be capable of standing the velocities which the water will attain.

After an inspection of the principal systems of regulation in Italy, France, England, India and Egypt, I am of opinion that the only system of regulation capable of working on the scale and under the conditions imposed on us in the Nile valley, are Stoney's patent self-balanced roller gates. I have seen these gates working in Ireland and England, and tested at Ipswich a pair of them for Holland. After a theoretical examination of the subject with Professor Benetti of the University of Bologna, and an exhaustive practical examination with Mr. F. D. M.

* 'Nile Reservoirs,' report by Sir Colin Scott-Moncrieff, Col. Ross and Mr. Willcocks, Cairo, 1891.

† Report of the Nira Canal Works, Bombay 1892, page 18.

‡ Report on the Nira Canal project, Bombay 1892, page 18.

Stoney, M.Inst.C.E., I have concluded that gates 2 metres wide and 10 metres high will best meet our requirements. With such gates under 22 metres head of water, the working pressure upon the rollers can be easily maintained at one-third of a ton per lineal inch, which is Mr. Stoney's safe limit. We shall also be able to dispense with arches and cover the sluices with granite lintels. All cut stone arches which are heavily loaded on the crown are liable to settlement, and leak when under a great head of water. A lintel is the safest and soundest covering when only ashlar is employed."

Before giving a detailed description of the dam actually under construction at Assuân, I shall give selections from the reports accompanying and following the project of 1894. The first selection is from a report by Sir John Rogers, Director-General of Sanitation, entitled 'The Sanitary Aspect of Nile Reservoirs,' published in 1894:—

"On the question of the quality of the water retained in the reservoir above the dam, various opinions have been expressed. The pessimist view represents the sanitary difficulties as insuperable; a horrible picture is drawn of a stagnant pond into which is delivered the putrescent drainings of equatorial swamps, swarming with bacterial life, the sole water supply of the country.

I cannot share these views. The sources of the White Nile, the main tributary, are 3500 kilometres from Khartoum, from Khartoum to the proposed reservoir is 1809 kilometres.

At the junction of the Gazelle River and the White Nile, 1,000 kilometres above Khartoum, occurs the pollution with decaying vegetable matter, which imparts a colour to the water as far north as Cairo at certain times of the year.

No proof exists that the green water on its arrival at Cairo has ever produced any special diseases. I do not pretend that it is a water supply which would be selected for choice, but it is the water which for a very brief period has hitherto been the sole supply of the country.

The Nile has considerable power of so-called self-purification. In the 2,000 kilometres between the source of pollution with the vegetable organic matter, and the delivery of water into the reservoir, the process of purification would be going on, and it is not too much to expect that in this distance the water would have lost much of its noxious quality.

Dr. Stevenson, the official analyst of the Home Office, after an exhaustive examination of the question of purification, writes as follows "Altogether, then, the natural purifying agencies going on in streams are in the aggregate enormous, and generally effective." (A Treatise on Hygiene and Public Health).

Mr. Garstin points out that the so-called poisonous water being delivered into the reservoir would be so diluted with the pure water already in the reservoir, that its deleterious influences would be diminished rather than increased.

It must not, however, be forgotton that the pure water with which the reservoir was originally filled will be gradually drawn off, and its place taken by the less pure water coming in at the head of the reservoir. The discharge at the outlet will always be greater than the discharge of the river at the inlet. The head of the reservoir will be about 180 kilometres above the dam. The water being delivered at the head will be gradually decreasing in purity as the Nile falls, and will affect

the general purity of the mass of water in the reservoir. As to the extent to which this will take place, it will depend on the discharges at the inlet and outlet and the consequent velocity in the reservoir, as well as on the rules governing the mixing of masses of water under various conditions, which can be more fitly dealt with by the technical Commission of Hydraulic Engineers. I would confine myself to stating that we must expect a gradual deterioration of the quality of the water stored in a Nubian reservoir as the summer months go on, but it is a question whether this deterioration will ever amount to the actual deterioration of the Nile without any reservoir. On the other hand, below the dam we would have an increase in quantity and a far greater velocity, both of which would tend to raise the quality of the water above its present standard during Low Nile.

Infiltration plays such an important part in the sanitary condition of the country, that the effect of any new irrigation works is naturally an object of anxiety to this department.

We have seen how at Ismailia, a town may be waterlogged by a high-level canal.

The birkets in the country are produced by Nile or canal infiltration. Cemeteries may be flooded and the subsoil water of villages raised by the proximity of a canal, but such results generally occur when irrigation and drainage do not go hand in hand.

When the high-level canal at Ismailia was constructed, had the drainage of the subsoil of the town been considered as a portion of the work, the town would not have suffered as it has done from fever. It is satisfactory to note, then, that the importance of drainage is thoroughly recognised in the works associated with the new reservoir.

There must be a great temptation in dealing with large irrigation questions, to reduce all results to cotton or sugar cane. I would only ask that human life should be given a small place in the calculations. It might be worthy of consideration whether, before the line of a canal was finally decided on, it might not be referred to the Sanitary Department for an expression of an opinion—not for a moment as implying that the Irrigation Department is incompetent to deal with sanitary aspects of the question, but lest the greatness of the results expressed in cotton or sugar cane dwarf into forgetfulness the question of public health, in which this department is interested."

After an exhaustive review of the report of 1894, Sir William Garstin recommended the Assuân reservoir at R.L. 114·00 and referred the question to a technical commission composed of Sir Benjamin Baker, K.C.M.G., M. Boulé, and Signor Torricelli, from whose report I extract the following :—

"The Commission is in accord on the following important points :—

(*a*) That the valley of the Nile itself offers many advantages over the Wadi Rayan as a site of a storage reservoir.

(*b*) That the dam should not be solid, but have openings controlled by sluices of sufficient area to pass the heaviest floods.

(*c*) That there are no engineering difficulties in constructing such a dam in the Nile valley and securing its permanent stability.

(*d*) That there are no sanitary objections to such a reservoir.

The Government proposes a dam provided with numerous and very large under-sluices which would pass the entire flood waters heavily charged as they would be with deposit. The commission recognises the necessity of such a work in order that the muddy waters of the Nile flood might traverse the dam without parting with the matter held in suspension, as it is on this matter that the richness of Egypt in great part depends. The Commission is of opinion that any solid dam, which closed the Nile valley and raised very considerably the level of the Nile in flood, would result in a silting up of the reservoir and hurt severely the irrigation of Egypt. It is clearly proved in the report that the Nile in winter has abundance of water to spare for storage and subsequent use in summer, and the table given in Rogers Pasha's report shows how gradually and easily this can be done without any serious disturbance of the régime of the Nile.

The Commission is of opinion that a dam pierced by under-sluices could be constructed in the valley of the Nile, and that it would present no difficulty which the science of engineering could not master. The building materials at hand are good and reliable, and those to be imported from Europe could be easily and economically transported to the site of the work. Such a work could be made so secure that its permanent stability would be assured, and it would be absolutely no source of danger to the country.

Rogers Pasha, the Director-General of the Sanitary Department, has published a report on the sanitary aspect of the proposed Nubian reservoirs, and the Commission accepts completely the following conclusions enumerated in the note of Rogers Pasha dated March 1894.

(*a*) The summer discharge of the Nile, downstream of the reservoir, will be augmented from the 5th May to the 25th July, and this will constitute a gain to the country from a sanitary point of view.

(*b*) The winter discharge of the river, during the filling of the reservoir, will be diminished, but not to an extent sufficiently great to prejudice the public health.

(*c*) The quality of the water in the Nile and in the reservoir will gradually deteriorate as the summer advances, but this deterioration will be less than that which takes place now that there is no reservoir.

(*d*) Special precautions should be taken to prevent the pollution of the reservoir, and the Commission points to the removal of the cemeteries as one of the precautions which should be adopted (mentioned in paragraph 24 of Rogers Pasha's note).

The majority of the Commission, composed of Sir Benjamin Baker and Signor Torricelli, is of opinion that the studies of the Nile valley and of the reservoir question in general by the large staff of Government engineers employed on this work during the past four years, coupled with the personal inspection of the river up to Wadi Halfa made by the Commission itself, renders it possible for them to make at once a selection from the different projects submitted for their consideration.

As regards the design and construction of any dam across the Nile valley, the majority of the Commission is of opinion that the absolute security of the work must be the first consideration. The conditions to ensure this are :—

(1) A solid rock foundation to support the masonry and to resist the action of the water.

(2) A considerable length of dam, so that the openings may not be close together, that the stability of the work may approach as nearly as possible to that of a solid dam, and that at the same time the action of the water may not be concentrated but be distributed over a great width of the river bed.

(3) Shallow water, so that the total height of the dam above the foundation may be as small as possible.

The majority of the Commission considers that there is no site in the Nile valley between Cairo and Wadi Halfa complying with the preceding conditions, except the site indicated by the Government engineers at the head of the first cataract downstream of Philæ Island, and it unhesitatingly recommends the adoption of that site.

Two other sites have been taken into consideration by the Government. They are *Silsila and Kalabsha.*

The majority of the Commission considers the Nubian sandstone at *Silsila*, with its strata of clay, which could be dissolved and removed under a great head of water, as unfit for a dam over 10 metres in height. For an open dam, such as those proposed for the Nile, they reject the Nubian sandstone as absolutely unsafe.

As regards *Kalabsha*, it is of opinion that although the rock is all that could be desired, the great depth of the water and the narrowness of the river render the construction of a dam practically impossible on account of its immense cost. During the working season the depth of water would be over 22 metres, and coffer-dams as proposed by the Government would be an impossibility. The foundations would have to be put in by compressed air, and as the dam would have a final height of 49 metres and be subjected to water pressure, the class of work would be enormously expensive. In addition to this, it would be necessary to execute extensive tunnels and cuttings through the granite hills to provide the waterway, and this again would be costly.

As regards the general design of the dam, the majority of the Commission approves of a single dam as proposed by Government. It is of opinion that the only means of storing, in Egyptian territory, the large quantity of water needed for the perennial irrigation of Egypt is the construction of a high-level reservoir.

While the majority of the Commission accepts in principle the Government project of a single dam, it proposes the following rules and modifications of some of the Government proposals, in order to ensure the absolute stability of the work:—

(1) The maximum height of the open dam to be 35 metres and never greater. This is also the maximum adopted by the Government engineers.

(2) The maximum head of water to be 25 metres as proposed by Government.

(3) The widths of the openings to be 2 metres as proposed by Government, but the widths of piers to be 5 metres instead of 3 metres.

(5) The maximum pressure on each pier of 7 metres must be everywhere 5 kilogrammes per square centimetre, and there must be no tension anywhere. The calculation of each pier must be made independently of the support received from the dam between the piers when the calculations for the 'full reservoir' are being made. For the 'empty reservoir' calculations the dam between the piers will be considered. The water level must be taken as 3 metres above the maximum full water level of the reservoir, to allow for waves and accidental rising of the water surface.

(6) Each 2-metre wide opening is to consist of 2 sluices. Each sluice to be 3·75 metres high with one immediately above the other. The area of waterway of the two sluices, or of one opening, to be exactly 14 square metres.

(7) Each opening to be regulated by a sluice gate 8 metres × 2 metres.

(8) In the Government designs the sluices are lined with granite ashlar, but the majority of the Commission is of opinion that cast iron, 35 millimetres in thickness, would be far preferable. The employment of cast iron would not necessitate the importation of much skilled labour from abroad; it would permit of a far more perfect joint between the sluice and the regulating apparatus; and its use would reduce the time needed to build the dam.

Cast-iron linings would not be more expensive than granite ashlar, while the time needed to dress and build the granite ashlar would be three times that needed to cast and put up the pipes.

The length of the dam at Assuân proposed by the majority of the Commission is exactly the same as that proposed by the Government. The modifications introduced by the former result in a better distribution of the openings, with wider piers, and a greater power of scattering the water as it issues from the under-sluices. The length of the dam will be unaltered and the cost in consequence will not be increased. The increase of cost, owing to the modifications of the Commission, has nothing to do with the length of the dam, it is owing to the fact that the maximum pressure has been lowered from 6·5 kilogrammes per square centimetre to 5 kilogrammes per square centimetre, and the water surface for purposes of calculation has been raised 3 metres.

The majority of the Commission thinks that the velocities of 4 metres per second in mean maximum floods, and of 7 metres per second in times of extraordinary flood, are absolutely safe for cast-iron pipes. In existing dams, notably at Nira, velocities are much higher than those quoted, and they traverse sluices lined, not with cast iron, but with granite. The objection to a single dam on this head is groundless.

The majority of the Commission thinks that a head of water of 1·75 metre in August, when the Nile is heavily charged with deposit, of 2 metres during the interval of a mean maximum flood, and of 4 metres during extraordinary floods, which come only two or three times for a few days during a period of 20 years, will not cause a silting up of the reservoir sufficiently serious to modify the capacity of the reservoir or hurt the agriculture of Egypt by depriving the water of deposit. The bed of the Nile will be slightly raised, but as the water in the reservoir will not be utilised below a level 4 metres above the present minimum summer, the small amount of mud deposit will in no way affect the capacity of the reservoir.

The Government has before it a good project, worthy of all confidence, a project which even the member of the Commission differing from the majority considers 'realisable,' although he 'cannot associate himself with any propositions for inundating or even modifying in any manner whatsoever the relics of the Temples and other buildings raised in ancient times on the island of Philæ, because, in doing so, he would be certain to be despised, not only by his own countrymen, but by the public opinion of the whole of Europe.

Neglecting the question of Philæ, a question on which the Government has not asked the Commission for an opinion, the majority of the Commission recommends a single dam pierced by numerous sluices lined with cast iron, as the best and safest

solution of the question of reservoirs. It accepts also the Assuân cataract as the best site. It persists in its belief that there is no necessity for it to advise the Government to make further studies in order to discover better projects or better sites, for it is convinced they do not exist."

Reviewing the report of the Technical Commission, Sir William Garstin, K.C.M.G., Under Secretary of Public Works, wrote as follows :—

"The majority of the Commission concludes by saying that it recommends a single dam pierced with numerous under-sluices as the best and safest solution of the reservoir problem. It accepts the Assuân cataract as the best, and indeed as the only practicable site for the construction of such a dam.

It insists that it would be a waste of time for the Government to make further studies in order to seek better methods of design, or better sites, as it is convinced that none such exist.

Sir Benjamin Baker and Signor Torricelli have discussed so ably and thoroughly all the questions submitted to the Commission, that I have practically nothing left to add. I can only endorse every word they say with respect to the single dam at Assuân, which project was that submitted by Mr. Willcocks and approved of by me. I can only express my great satisfaction that our proposals have been approved by men so eminent in their profession as the two gentlemen above named. As regards the modifications proposed by them, there can be no question as to their adding to the stability of the dam, and the Egyptian Government may well feel satisfied that, before committing itself to any scheme it has obtained the opinion of two such distinguished men. I conclude by offering my most sincere thanks to the three members of the Commission for the way in which they have devoted their time and labour to the preparation of the very valuable reports with which they have favoured us.

I come lastly to that portion of the subject which with a large number of persons is doubtless the most important, as it certainly is the most difficult, question of all those to be solved. I may say at once that after reading Messrs. Baker and Torricelli's report I completely share their opinion that the Assuân cataract site is the only possible one for a reservoir dam, and further that a single dam of sufficient height to store water for the wants of Egypt is the only possible solution of the reservoir problem as far as that portion of the Nile valley that lies between Cairo and Wadi Halfa is concerned. The Government of Egypt must then decide either to construct a single dam at Assuân or to postpone the question altogether until that portion of the river lying to the south of the present Egyptian frontier has been thoroughly explored and studied. If its decision be in favour of the former solution, it must also decide as to what is to become of the Philæ Temple. As regards this part of the question, I have little to add to the opinion I expressed on the subject in my previous note. When I wrote my first report I thought and hoped that possible alternative sites existed, but the report of Messrs. Baker and Torricelli clearly shows that such is not the case, and that the dam, if made, can only be made at Assuân. This narrows the question to very small limits, and leaves the Egyptian Government face to face with the problem as to what is to be done with Philæ. If the dam be made at Assuân the Temple must either be raised, removed or submerged. I have already suggested its removal to the island

of Biggeh, and Sir Benjamin Baker suggests raising it to such a height as to place it above the level of the highest flood water. Mr. Somers Clarke, the well known archæologist, has suggested a third alternative. This is that if it be decided to leave the Temple where it is, which in the case of the dam being made would result in its annual submersion, a complete archæological survey and investigation be made of Nubia, and that accurate drawings and surveys should be made of all such relics of interest as would be submerged by the reservoir: that such of these monuments as would bear transporting should be transported to the Cairo Museum, so that if the submersion of these remains be decided upon as unavoidable, as much should be done as lay in our power to record them and preserve their interesting features from obliteration. Should this proposal be carried out, I would suggest that Monsieur de Morgan be asked to undertake the work, and that a sum of say 50,000*l.* be added to the dam estimate to cover the expenditure required.

It is of course for the Egyptian Government to decide upon this point, and to it I leave the question. It must duly weigh the sentiment connected with the Temple and its surroundings, against the benefits to be derived by the country in general from the construction of the reservoir. I trust, however, that we, its advisers, who are so unfortunately thrust into the position of having to recommend a work that will involve possible damage to one of the most beautiful monuments in the world will, if not now, be some day acquitted of having done this wantonly and without regret.

The Egyptian Government, pressed hard by archæologists, finally decided to lower the water surface of the reservoir from R.L. 114 to R.L. 106 metres, and to make an effort to save Philæ Temple. This action of the archæologists has hurt the reservoir and will not in the end save the temple. If either our proposal to remove the temple to the adjoining island of Bigeh, or Sir Benjamin Baker's proposal to raise it vertically upwards on its own base had been adopted, Egypt might have had a reservoir two and a half times as capacious as the one under construction, and capable of settling for a generation the irrigation question of the country, and moreover the temple would have been preserved for all time.

During the execution of the Tiber improvement works at Rome, I saw the Italian engineers dismantling and putting together stone by stone, exactly as it was before, an important masonry bridge of large span which dated from the time of the Republic, and was an object of the most cherished regard. They were preparing to treat the St. Angelo bridge in the same way. The "Bigeh" island was admirably suited for the site of a temple, and well above the high-water level of the largest reservoir.

The following selections are from my final report of 1895 :—

"*The original project for a Reservoir for Egypt*, described in 'Perennial Irrigation and Flood Protection for Egypt,'* was submitted to a technical Commission whose report was printed by the Egyptian Government.† The Commission proposed

* Perennial Irrigation and Flood Protection for Egypt. Cairo, 1894.

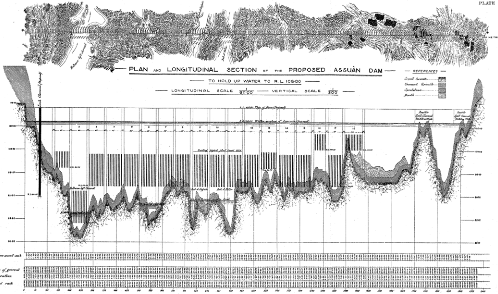
† Report of the Technical Commission on Reservoirs. Cairo, 1894.

certain modifications which affected the stability of the dam; certain other modifications which affect the size of the reservior have also been introduced to meet the views of archæologists and men of science. The final designs and specification which accompany this report have been drawn up in accordance with the decision of Sir William Garstin, K.C.M.G., and in consultation with Sir Benjamin Baker, K.C.M.G.,F.R.S.,who has been appointed consulting engineer to the works by the Egyptian Government. In my original report I had recommended a reservoir at the first cataract, with its water service at R.L. 118·00 metres, storing 3,700,000,000 cubic metres of water. In case the first cataract were not adopted for the reservoir dam, I recommended the construction of regulating works at the rocky outlets of Lakes Albert and Victoria (especially the former). The authorities at Lakes Albert and Victoria were requested to erect gauges on those lakes and have them recorded, so that the conditions of supply at the sources of the White Nile between January and May might be compared with the discharges of the Nile at Assuân between April and July. Since then we have further considered the problem, and have concluded that whether the sources of the Nile or the sills of any of the other cataracts of the Nile are utilised for water storage, it is absolutely necessary, in the interests of irrigation, to have near at hand, at the point where the Nile enters Egypt, a reserve of water to meet any contingencies which might arise. These contingencies would arise from the fact that some of the more important summer crops are incapable of standing a ten days' drought, while the summer discharges of the reservoirs would probably take eleven days to reach the canal heads from the first cataract, twenty days from the second, twenty-three days from the third, thirty-three from the fifth, thirty-nine from the sixth, and ninety days from Lake Victoria.

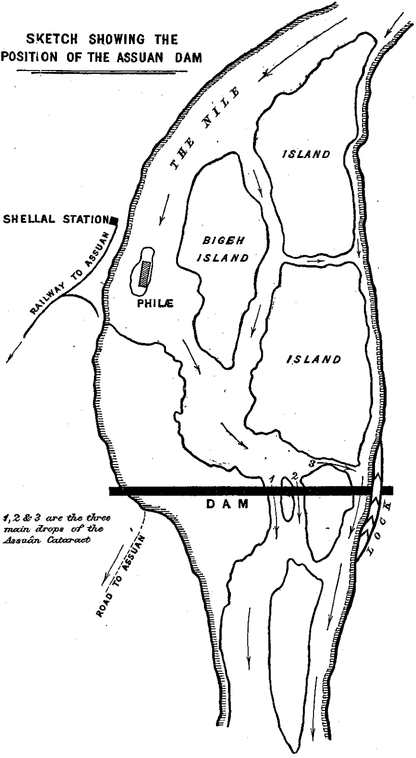
2. The *reservoir dam* will be constructed across the head of the Assuân cataract. This is the only site where a work of the nature of a dam can be constructed with perfect safety in the Nile Valley north of Wady Halfa. The maximum upstream water level will be R.L. 106·00 metres, and the minimum level on the downstream side will be R.L. 86·00 metres. The greatest head of water will be 20 metres.

The storage capacity of the reservoir will be 1,065,000,000 cubic metres. The reservoir will be filled between November and April, after the floods have passed, and will be discharged during May, June and July.

The reservoir will contain 1,065,000,000 cubic metres of water. The loss by evaporation during April, May, June and July will be 1 metre vertically, and will represent 7 per cent. of the contents of the reservoir, or 75,000,000 cubic metres. The net amount discharged by the dam sluices at Assuân will therefore be 990,000,000 cubic metres per annum. Between Assuân and Assiout, where the canal head will be situated, there will be a waste of water in raising the water surfaces of the river itself on a length of 530 kilometres and mean width of 400 metres by a height of 50 centimetres. This will mean a loss of 106,000,000 cubic metres; and if we estimate the quantity absorbed in the dry sandy bed of the river, which has a further width of 350 metres, as half this amount, the total loss of this head amounts to 159,000,000 cubic metres per annum. As Assuân is 530 kilometres from Assiout, and the Nile, when discharging its mean minimum of 410 cubic metres per second, has a section of 910 square metres, consequently the water has a velocity of 0·45 metre per second, or 40 kilometres per day, and takes 13½ days


PLAN AND LONGITUDINAL SECTION OF THE PROPOSED ASSUÂN DAM
TO HOLD UP WATER TO R.L. 106·00
LONGITUDINAL SCALE 1/5000 — VERTICAL SCALE 1/300
REFERENCES
Sound Granite
Unsound Granite
Sandstone
Earth
Depth of water on sound rock
Level of surface of ground
Depth of Excavation
Level of sound rock
METRES

SKETCH SHOWING THE POSITION OF THE ASSUAN DAM



to travel from Assuân to Assiout. Since seasons vary and demand springs up suddenly on occasions and has to be met, it will be necessary, as a matter of precaution, to start the water at a greater rate and at an earlier date than that demanded for each individual increase. The quantity of water thus wasted will bear some relation to the time consumed in traversing the distance between the reservoir and the canal head, and to the amount of mean daily discharge. At the Assuân dam 990,000,000 cubic metres of water will be discharged in 100 days, or at a mean rate of 10,000,000 cubic metres per day, and it will take 13½ days to reach Assiout. If we take one-half as the amount which will be annually lost, increasing proportionately to the demand, the estimate may be considered reasonable. This loss will thus amount to 68,000,000 cubic metres per annum. Adding up the losses between the dam and the canal head, we have a total loss of 227,000,000 cubic metres, which *leaves* 763,000,000 *cubic metres per annum as the net quantity which will be capable of utilisation.*

4. The proposed work is *an insubmergible masonry dam* pierced by 140 under-sluices of 14 square metres area each, and by 40 upper sluices of 7 square metres area each. The total area of opening will be 1960 square metres for the under-sluices and 280 square metres for the upper sluices, or 2240 square metres in all. The dam will have a total length of 1950 metres on one perfectly straight line, and will be founded everywhere on the soundest granite rock of the cataract. The maximum head of water will be 20 metres, and the maximum height of water will be 28 metres. The width of the dam at top will be 7 metres, and at bottom 24·50 metres. The calculations have been made in accordance with the recommendation of the Technical Commission, which recommendation was to the effect that the maximum theoretical pressure on the downstream toe of the dam when subjected to its maximum strain was not to exceed 5 kilograms per square metre; that the openings were not to be greater than 2 metres in width; and that the piers were not to be less than 5 metres in width. The 140 under-sluices will be lined with granite ashlar, and the 40 upper sluices with cast iron. The sluices will be 2 metres wide and 7 metres high, worked by Stoney's patent gates. Ordinarily, the sluices will be 7 metres apart centre to centre. Every tenth sluice and its neighbour will, however, be 12 metres apart centre to centre. The navigation will be effected by means of a canal provided with locks and traversing the extreme left flank of the dam. During the whole of the flood all the sluices will be fully open, and the flood waters of the Nile will be discharged through them. The maximum discharge of an extraordinary flood is 14,000 cubic metres per second, and this will traverse the sluices of the dam with a velocity of 6·25 metres per second and a head of 3·30 metres. The mean maximum flood of the Nile at Assuân is 10,000 cubic metres per second, and this will be discharged with a velocity of 4·75 metres per second and a head of 2 metres.

The muddy August flood of 8000 cubic metres per second will be discharged with a velocity of 4 metres per second and a head of 1·50 metre.

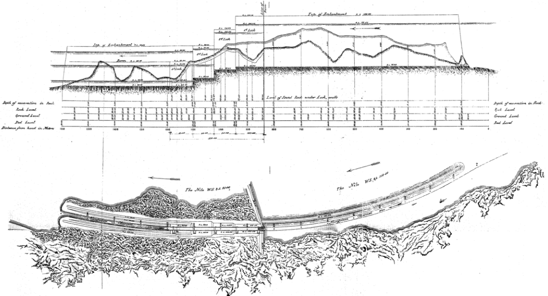
The *navigation channel*, with a total length of 1600 metres, will be on the left bank, and will be partially excavated out of the living rock and partially banked. The intake will be well removed from the draw-off water on the upstream side of the dam, while the outlet will be similarly removed from the wash on the downstream side. The bed width will be 15 metres. When the channel is in cutting, it

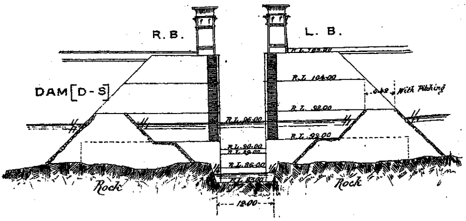
PROPOSED ASSUÂN DAM

NAVIGATION CHANNEL AND LOCKS

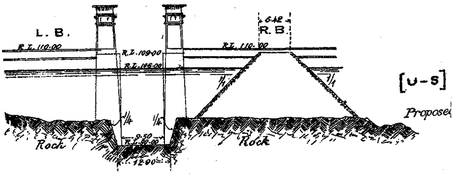
SCALE FOR PLAN AND LONGITUDINAL SECTION = 1/5000

SCALE FOR VERTICAL SECTION = 1/500





—— END VIEW OF LOCKS LOOKING U-S ——



—— END VIEW OF LOCKS LOOKING D-S ——

will be provided with continuous floating balks of pine on either side, in order to protect boats and steamers from the rough surface of the blasted granite.

The Locks.—The total drop of 21 metres will be divided into three drops of 6 metres each and one of 3 metres. The locks will have a clear length of 75 metres each and a width of 9·50 metres. The lock gates will range in height between 19 metres and 9 metres. The excessive height of the upper lock gates is rendered necessary by the fact that navigation has to be kept open when the reservoir is full as well as when it is empty. Considering the height of the gates, it has been considered advisable to adopt the plan recommended for the Nicaragua Canal, and to have single-leaved gates rolling back into recesses at right angles to the direction of the lock. Mr. F. G. M. Stoney, M. Inst. C.E., who designed the sluice gates, has designed the lock gates to meet all the requirements. His special report on the gates is contained in the specification. A lift bridge, hinged on to and in continuation of a fixed bridge over the recess, carries a pair of rails. On this railway travels a carriage supported by numerous rollers. From the carriage is suspended the lock gate. When the lock is open, the lift part of the bridge stands vertical and the gate is suspended within the recess. When the lock has to be closed, the lift bridge is lowered and spans the lock, the carriage carrying the gate is rolled across the lock, and the lock gate rests against the steel quoins at the sides and the steel sill at the bottom. The great depths which will exist at all times when the different gates are being worked, will lend themselves to the filling and emptying of the locks by means of valve openings in the gates themselves. As a matter of extreme precaution, every single gate has been designed of sufficient strength to stand a head of water equal to its own height. The lock walls will have a batter of 1 in 25, and in width are equal to half their height. Indeed, in every calculation every contingency has been allowed for, and extreme factors of safety have been uniformly adopted. It must, moreover, be borne in mind, that where the lock gates are 19 metres high, the maximum head of water in actual practice will be only 3 metres; while the top 12 metres alone of the height of the wall will be of masonry, since the bottom 7 metres will be blasted out of the solid granite rock."

The estimate of the cost of the work is as follows:—

Dam.

	cubic metres			
Excavation	62,000	at	£·20	= £12,400
Rubble masonry	300,000	at	1·00	= 300,000
Granite ashlar	26,000	at	7·00	= 182,000
Sandstone ashlar	24,000	at	3·00	= 72,000
Brickwork	5,000	at	1·50	= 7,500
	square metres			
Regulating apparatus	2,400	at	£75	= 180,000
Coffer dams and pumping				= 80,000
Total				£834,000

Lock.

	cubic metres			
Excavation . .	. 125,000	at	£·20 .	. = £25,000
Rubble masonry .	. 21,000	at	1·00 .	. = 21,000
Brickwork . .	. 21,000	at	2·00 .	. = 42,000
Granite ashlar .	. 1,000	at	7·00 .	. = 7,000
Sandstone ashlar .	. 1,000	at	3·00 .	. = 3,000
	square metres			
Lock gates . .	. 600	at £75	.	. = 45,000
	Total . . .			. £143,000

Dam	£834,000
Lock	143,000
Total . . .	£977,000
Contingencies at 10 per cent. and land compensation	248,000
Grand total . .	£1,225,000

Cost of water stored per 1000 cubic metres . . . . . $= \frac{1,225,000 \times 1000}{1,015,000,000} = £1·20.$

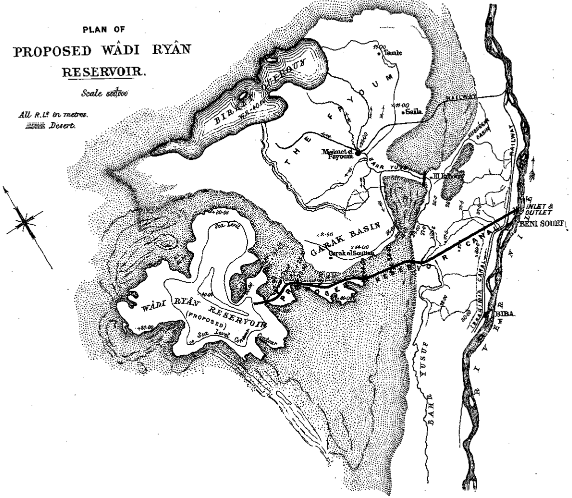
The water capable of utilisation will only be three-quarters of this quantity, as shown on page 440, but as the reservoir level can be raised 1 metre to R.L. 107·00, we may consider 1,015,000,000 as the quantity capable of utilisation.

It will have been noticed that the under-sluices as originally designed were to have been lined with ashlar; subsequently the Technical Commission proposed cast iron, but at my urgent request Sir Benjamin Baker allowed the final design to be made with granite. Now that the works have commenced it has been decided by Mr. Wilson, the Director-General, to line 20 of the 140 under-sluices with cast iron, in order to ensure the first year's programme. The cast iron is to have a thickness of from 35 to 38 millimetres, in plates of 1·50 metre × by 1·90 metre. For the side walls the plates are to have each two vertical ribs 30 centimetres deep, bonded into the masonry with cored out holes. The plates are connected together at the vertical webs only, by two 38-millimetre bolts, with a layer of felt between the flanges of the vertical ribs 3 millimetres in thickness. By this means it is expected that each plate will expand and contract independently like a block of ashlar. The bottom plates are 2·70 metres by ·75 metre, set with 3 millimetres of felt between the joints. Each plate will have one web at the back of the plate, 30 centimetres deep, bonded into the masonry. The bottom plates will not be bolted to each other, but each will be bolted at

PLAN OF PROPOSED WÂDI RYÂN RESERVOIR.

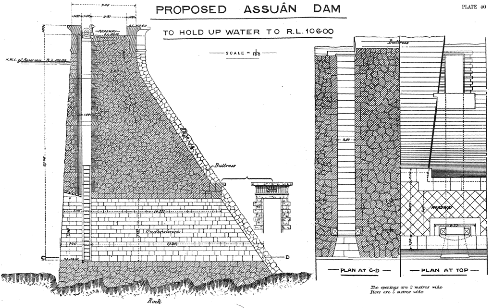
Scale $\frac{1}{500,000}$

All R.Ls in metres.
Desert.

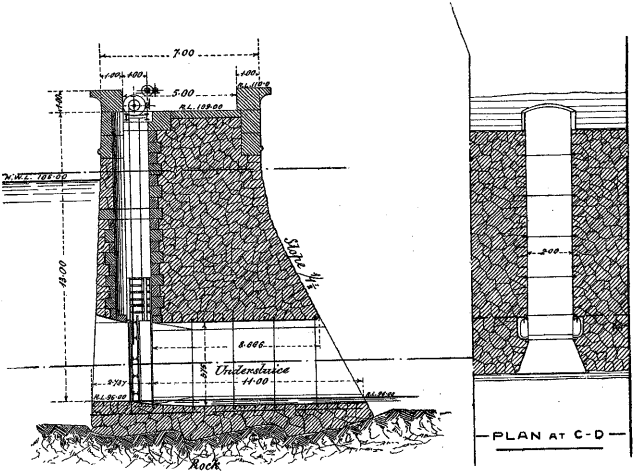


PROPOSED ASSUÂN DAM

TO HOLD UP WATER TO R.L. 106·00



CROSS SECTION OF UNDERSLUICE AT R.L. 84·00



CROSS SECTION OF UNDERSLUICE AT R.L. 96·00

SCALE = 1/150

either end to the vertical plate directly above it, in the same manner as the other parts of the vertical plates.

In the final design of the dam it was proposed to regulate all the under sluices by Stoney's self-balanced gates. It has since struck me that it would be wise to regulate twenty of the lowest sluices by Stoney's gates worked by screws as at Belleck. A reserve of power like this would be a wise provision to meet every kind of contingency.

Having finished with the reservoirs in the valley of the Nile, *we now come to the possible reservoirs outside the Nile valley.* The following quotation is from the report of 1894 :—

"After a careful examination of the deserts on both banks of the river between Wady Halfa and Cairo, I have found no depression in the deserts outside the Nile valley capable of being utilised as a reservoir except the Wady Rayan.

The Wady Rayan Reservoir.—Plate XLIII.A gives the plan of the Wady Rayan, the deserts between it and the Nile valley, and the cultivated land. The plan was begun by Colonel Western and has been completed by me. The Wady Rayan is a depression to the S.W. of the province of Fayoum. Its lowest point is 42 metres below sea level. It is separated from the Fayoum by a limestone ridge which is generally from 34 to 60 metres above sea level, except at two places where it falls to 26 metres above sea level on a length 600 metres. At R.L. 27 the Wady and adjoining depressions have an area of 673 square kilometres and contain 18,743,000,000 cubic metres. Between them and the Nile valley lie 30 kilometres of desert, of which 11 kilometres are occupied by a marked depression discovered by Liernur Bey in 1887. At the extreme western edge of the Nile valley, which is here some 20 kilometres wide, flows the Bahr Yusuf, and at the extreme eastern edge is the Nile. I propose to put the Nile in communication with the Wady Rayan by means of an inlet and outlet canal combined, for both filling the reservoir and discharging its waters.

Along the line of the canal there are alternating strata of sandy clay and clay to a depth of 10 metres. Near this line lie the ruins of Ahnessa (Herakliopolis) the ancient capital of the island Nome of Egypt. The island has to-day disappeared, but the sandy character of the strata bears witness to the increased velocity given here to the Nile flood by the draw of Lake Mœris. The gradual disappearance of the lake was accompanied by the gradual silting up of the western channel of the Nile. The soil along the outlet canal is inferior to that ordinarily met with in Egypt, and the spring level is in places near the surface. As this canal will run with a severe velocity, allowance has been made in the estimates for pitching its bed and slopes. On leaving the Nile valley and entering the deserts, we meet with sand at the surface, or sand conglomerate with gypsum and salt, and then a yellow marl with Epsom salts, and finally a bitter plastic clay of a black colour overlying the Parisian limestone. The clays and marls are most extensive in the narrow neck of land between the Nile valley and the Fayoum, and for a distance of some 10 kilometres south of it. They rise to a height of 70 metres above sea level. There are none of these marls inside the Wady Rayan or in the depressions connected with it, but as they have to be traversed by the canals they constitute a very serious factor in the question of the Wady Rayan reservoir. They are extraordinarily easily dissolved in

water, and it is on their account that I have chosen the alignment of the inlet canal along the Bahr Bilama, where we have only 2,500 metres of them, instead of along the alternative line, where we have no less than 9 kilometres. No embankment could in my opinion be constructed of these salty marls and bitter clays which could hold up water for any length of time.

A narrow neck of land, some 15 kilometres in length, runs between the Fayoum and the depressions traversed by the Wady Rayan canal. This neck of land is in continuation of the salty marls and clays, but the limestone is near the surface and is overlaid with a thin skin of sand and pebbles. Its northern slope is covered with the Nile corbicula shells at a level of about 22·50 metres above mean sea, while the plain at its foot contains strata of compact fresh-water shells. The southern slopes are devoid of fresh-water remains of any kind. It is evident from this that the ancient Lake Mœris which covered the Fayoum rose to a level of about 22·50 metres above mean sea, while the Wady Rayan has never had Nile water in it. The limestone in Wady Rayan and neighbouring depressions is inferior to that at the Tura quarries, and is strewn thick with nummulites (principally the nummulitus Gizehensis). It is covered in places with rich deposits of gypsum and salt.

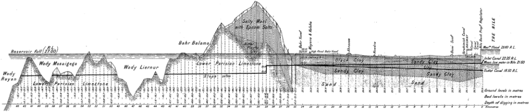
The Wady Rayan reservoir might be fed from the Nile or the Bahr Yusuf or from both, while it must discharge into the Nile. The Nile in flood runs so frequently at a level below that needed for flood irrigation that, if the reservoir were to depend on what it could obtain in flood, it would be unable to discharge an appreciable quantity of water in three years out of ten. If reference is made to the Cairo gauges, it will be seen that 1873, 1877, 1880, 1882, 1884, 1888 and 1893 were years in which the flood practically failed to attain a gauge 6·30 metres at Cairo, which is the minimum needed for effective flood irrigation, and that consequently in those years the reservoir would have failed. The remodelling of the basin feeders, recently carried out by Colonel Ross, has also resulted in a lowering of the Cairo gauge by 30 centimetres during the flood. Under these circumstances, it is as necessary for the Wady Rayan to draw its supply of water in winter (when there is never any deficiency) as it was necessary for the Nubian reservoirs. The natural source of supply in winter is the Bahr Yusuf, and, if there were no question of filling the Wady Rayan between R.L. − 42 and R.L. + 24, we might dispense with an inlet canal for the Nile. The inlet canal will, however, be needed to raise the level of the reservoir to R.L. 24, and make it ready to receive the top film of 3 metres which alone can be effectively discharged. The Bahr Yusuf takes its supply from the Ibrahimia Canal, which has its head at Assiout. The Bahr will be able to discharge 290 cubic metres per second, and be just within its banks in winter, when the weir is constructed across the Nile downstream of the Ibrahimia canal head. The Bahr Yusuf could not carry more than 260 cubic metres per second in winter, i.e. 30 cubic metres under full supply, without hurting the lands on its banks; and for a similar reason, the Wady Rayan reservoir cannot be maintained at a level above R.L. 27 without permanently injuring large tracts of country. Of the 260 cubic metres per second carried by the Bahr Yusuf, about 60 cubic metres per second will be needed for the irrigation of the Fayoum and other improved tracts, leaving 200 cubic metres per second (or 17,000,000 cubic metres per day) for the reservoir. By this means we shall ensure the filling to the reservoir *every year* to its full level of 27 metres above sea level. This is a matter of the greatest importance. Reservoirs which can only ensure a good discharge after high floods, when the supply in the

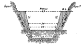
PLATE 43B

WADY RAYAN RESERVOIR.

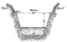
LONGITUDINAL SECTION OF PROPOSED INLET AND OUTLET CANALS.

HORIZONTAL SCALE 1/50000 VERTICAL SCALE 1/600

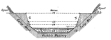




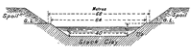
TYPE CROSS SECTION IN ROCK & MARL



TYPE CROSS SECTION IN ROCK



TYPE CROSS SECTION IN SALTY MARL



TYPE CROSS SECTION IN BLACK CLAY

SCALE FOR CROSS SECTIONS 1/500



Nile itself is abundant, and which fail after low floods, when the Nile is most in need of water, are not worthy of serious consideration.

I propose joining the Nile to the Wady Rayan by a single canal leaving the Nile a few kilometres north of Beni-Suef and traversing the intervening desert by the Bahr Bilama. At this point the mean low water is R.L. 21·50, and the high flood level 29·60. This canal will act as an inlet canal to the reservoir when it is being filled and having its water surface raised from R.L. −42·00 metres to R.L. +24·00 metres. During this time its head will be at R.L. 22·25, and slope $\frac{1}{20,000}$ into the Wady Rayan. It will be used thus for seven years. After the seventh year, when the reservoir is at R.L. + 24·00, the canal will be deepened from the edge of the desert to the Nile on a slope of $\frac{1}{10,000}$ backwards into the Nile. It will now act as an outlet canal only, for the reservoir will be annually replenished from the Bahr Yusuf independently of the Nile. Plate XLIII.B gives a cross section of this line, while Plate XLIII.A gives the plan.

The table on page 446 gives the areas and contents of the Wady Rayan reservoir at different levels. The evaporation will be 2·50 metres vertically per annum, and will be taken in the calculation as 2 metres in one year and 3 metres in the next. With these facts before us, we may calculate the time it would take to bring the reservoir up to R.L. 27·00, assuming that we began to fill in 1873–74.

The inlet canal in flood will discharge 230 cubic metres per second, and the Bahr Yusuf will give 200 cubic metres per second in winter.

230 cubic metres per second = 20,000,000 cubic metres per day.
200 „ „ = 17,000,000 „ „

1873–74. No supply in flood.
In winter 135 days × 17,000,000 = 2,300 millions.
The lake would rise to − 16·00, and owing to evaporation would be at − 19.

1874–75. In flood 90 days × 20,000,000 = 1,800 millions.
In winter 135 days × 17,000,000 = 2,300 „

Total . . . . . . 4,100 millions.

	The lake would rise to	− 1 − 2 = − 3.
1875–76 like 1874–75.	„ „	+ 9 − 3 = + 6.
1876–77 „ 1874–75.	„ „	+ 16 − 2 = + 14.
1877–78 „ 1873–74.	„ „	+ 19 − 3 = + 16.
1878–79 „ 1874–75.	„ „	+ 23 − 2 = + 21.
1879–80 „ 1874–75.	„ „	+ 27 = + 27.

After seven years the reservoir would be in working order. As we shall see in the next paragraph, it will be necessary for the reservoir to have its levels raised annually from R.L. 24 to R.L. 27. This means 2,000,000,000 cubic metres of water. During years of low flood the whole of this supply must come from the Bahr Yusuf in winter, which, as we have already seen, is capable of discharging 2,300,000,000 cubic metres. During flood the daily evaporation off the lake will be (650,000,000 × ·008) = 60 cubic metres per second, which can be spared from the Bahr Yusuf so as to maintain through the flood the level of the reservoir at a constant level.

We now come to the discharge from the Wady Rayan reservoir. In the matter of discharge this reservoir is handicapped as compared to the Assuân reservoir. It could supply a heavy discharge in May, but owing to the decreasing head, less in June and still less in July; while we want more water in July than in May. The Assuân reservoir having its sluices above the summer level of the Nile, can discharge much or little as required; and besides this, in a good summer it could keep its water and discharge it all in fifteen days at the beginning of the flood, and so immensely improve the maize crop by allowing it to be sown early. On the subject of the Wady Rayan reservoir, see Appendix II., where there are recorded some interesting observations by Dr. Schweinfurth.

CONTENTS OF THE WADY RAYAN RESERVOIR.

R.L.	Area in millions of square metres	Cubic Contents in millions of cubic metres.	R.L.	Area in millions of square metres	Cubic Contents in millions of cubic metres
+30	727	20,843	−1	294	5,844
29	709	20,125	−2	287	5,554
28	691	19,425	−3	280	5,270
27	673	18,743	−4	273	4,993
26	654	18,080	−5	266	4,723
25	636	17,435	−6	260	4,460
24	621	16,806	−7	253	4,204
23	607	16,192	−8	246	3,955
22	592	15,592	−9	239	3,713
21	577	15,008	−10	232	3,478
20	563	14,438	−11	225	3,249
19	546	13,886	−12	218	3,028
18	530	13,348	−13	211	2,813
17	513	12,827	−14	204	2,605
16	497	12,322	−15	197	2,404
15	480	11,833	−16	191	2,211
14	464	11,361	−17	184	2,023
13	447	10,905	−18	177	1,843
12	431	10,466	−19	170	1,670
11	414	10,043	−20	163	1,503
10	398	9,637	−21	152	1,346
9	388	9,244	−22	142	1,199
8	379	8,861	−23	131	1,062
7	369	8,487	−24	120	937
6	359	8,123	−25	109	822
5	350	7,769	−26	99	718
4	340	7,424	−27	88	624
3	330	7,089	−28	77	542
2	320	6,764	−29	66	470
1	311	6,448	−30	56	410
0 Sea level	301	6,142	−35	38	174
			−40	22	22

Between R.L. + 24·00 and R.L. + 27·00 the Wady Rayan reservoir contains 1,937,000,000 cubic metres. One-third will be lost by evaporation and loss of slope in the canal, leaving 1,300,000,000 to be utilised. The proposed canal could discharge this by giving 250 cubic metres per second in May, and 150 cubic metres per second in July. If it was desired to ensure 250 cubic metres per second in July, it would be necessary to widen the canal, which would cost 750,000*l.* more than the estimated cost of 2,280,000*l.*, or raise the total to 3,000,000*l.*

We will return now to the details of the design :—

The inlet canal will have a bed width of 40 metres and side slopes of 1 to 1½. At the 29th kilometre of the canal there will be a vertical drop of 4 metres, as we are here on rock; the bed will be reduced from 40 metres to 25 metres, since it is warranted by the discharging capacity of the section. On Plate XLIII.B are given the cross sections it is proposed to give in the different soils. In the clays and sands below high-water mark, I have given slopes of 1 vertical to 1½ horizontal; but above high-water mark, 4 vertical to 1 horizontal. This latter slope is very steep, but is the only one possible if the estimates are to be kept down.

The masonry works will be :—

1. Regulating Head.
2. Bahr Yusuf Crossing and Regulator.
3. Ibrahimia Canal Syphon and Railway Bridge.

The works will be founded entirely on sand and quicksand, and I have chosen the foundations of the Rayah Tewfiki head as a type. As the head of water will be very considerable and of long duration, the floor has been made everywhere 3·50 metres thick. The Bahr Yusuf regulator has been provided with a lock, as the canal is navigable. No locks have been provided for the reservoir canals. The project will cost 2,280,000*l.*

Abstract of Cost.

Excavation, inlet and outlet canal combined	£1,684,000
Masonry works	225,080
Masonry lining	43,750
Pitching	90,000
Closing depression	1,200
Land	30,000
	£2,074,000
Contingencies	206,000
	£2,280,000

Details of Cost of Excavation.

Inlet and outlet canal combined in	clay,	9,480,000 at	£·04 =	£379,200
" " "	marl,	7,592,000 at	·06 =	455,520
" " "	rock,	8,374,000 at	·10 =	837,400
" " "	sand,	602,000 at	·02 =	12,040
				£1,684,000

In making the estimates for the works connected with this project very low rates have been allowed, as I believe that the large quantity of work to be done will permit of it. I have not, however, allowed for scouring out the salty marls and

bitter clays by the force of the current itself, after a narrow channel has been dug through the hill. Such a channel might choke itself up and cause the loss of a year; while we all know that the water can either run full bore and fill the reservoir in seven years, or spend much of its time in cutting away the clay, and lengthen out the time of the filling of the reservoir. As the interest charges on the work will amount to 50,000*l.* per annum, I think it safest and best to execute the works completely as fast as possible, and get the reservoir into working order at the earliest date.

The cost of water stored per 1000 cubic metres $= \frac{2,280,000 \times 1000}{1,937,000,000} = 1 \cdot 14l.$

Cost of water capable of being utilised per 1000 cubic metres $= \frac{2,280,000 \times 1000}{1,300,000,000} = 1 \cdot 60l.$"

We now come to the third class of reservoirs, or reservoirs situated in the Delta. They may be called *basin reservoirs.* Of these reservoirs I wrote in 1894:—

"In my book on Egyptain Irrigation, and again in the report of 1891 on reservoirs, I proposed utilising many of the low depressions in the Delta and in the Fayoum as reservoirs, notably lake Edku in Behêra. Since writing, I have had no time to make any detailed surveys of these works, and can add nothing to what was then said. Further reading has convinced me of their practicability. Reference may be made to 'Hydraulique Agricole,' by De Cossigny, pages 53 and 55, Paris 1889; to 'Rivières et Canaux' by P. Guillemain, vol. 1, pages 230, 232, Paris 1885; and 'Les Irrigations' by A. Ronna, vol. 1, pages 276, 463, 472, &c., Paris 1889. Mr. Lang Anderson, the manager of the Lake Abukir Reclamation Company, has long studied the question of washing salted land in the Nile Valley, and placed the results of his experiments at my disposal. They confirm my previous impressions. When once the reclamation of the low lands has really begun, the value of these reservoirs, scattered among the lands themselves and directly available, will be appreciated."

The description of these *basin reservoirs* was given in detail in the Report of 1891:—

"It has been stated that Lower Egypt possessed 1,200,000 acres of land capable of reclamation, but lying at present as swamps and salted plains. The swamps could be converted into basin reservoirs for water storage by surrounding them with earthen banks, filling the reservoirs in flood, maintaining them at their full level throughout the winter, and utilising them during the sixty critical days of the summer. During flood the water would be allowed to sweep over the area and wash it, while in winter the canals would be tailed into the reservoir and fill it by the end of April or 15th May, up to which date there is never any lack of water in Lower Egypt. Between 15th May and 15th July the reservoirs would be drawn on. If the reservoirs were filled to a depth of one metre, 80 centimetres would be available for irrigation. Each acre of land in the reservoir would supply ($4200 \times \cdot 80 =$) 3360 cubic metres, and would itself, in the course of eight or ten years, become first-class land. The reservoir then might be sold as good land and planted with cotton, while the waste land in the neighbourhood might be converted into a

reservoir. This system would not only supply water, but also ensure reclamation on a large and thorough scale. The barrow pits from which the earth for the banks was taken would constitute good drainage cuts.

It is evident that the earthen banks will be exposed to the wash of the waves, which in March and April will be serious. Pitching the banks would be expensive. I estimate that it would amount to (1000 × 3 × ·4 × ·7) = 840*l.* per kilometre. It would permit of an extra depth of 30 centimetres of water in the reservoirs, and increase the quantity 40 per cent. The stone might also be used again and again for future reservoirs. Lining the sides of the reservoirs with brick masonry, such as the fellaheen use for their sakyas and which stands the wear and tear of water, would cost 420*l.* per kilometre; while protection by means of stakes and weeds will cost 100*l.* per kilometre. I propose the brick masonry system of protection for these basin reservoirs.

The estimate of the cost of a reservoir covering 12,500,000 square metres, which is an average sized basin reservoir, will be as follows:—

Earthwork, 165,000 cubic metres at 2 piastres .	. =	E. £3,300
Inlet culverts, two at 100*l.*	. =	200
Outlet „ one at 100*l.*	. =	100
Feeding channel	.	150
Brick masonry protection, 15 kilometres at 420*l.*	. =	6,300
		E. £10,050
Contingencies.	.	1,000
Total	.	E. £11,050

The amount of water contained in the reservoir will be 16,250,000 cubic metres, of which there will be utilised 13,750,000 cubic metres. As this water will be delivered at the point where it is required there will be no further losses in transit.

The cost of water stored per 1000 cubic metres will be $\frac{11,050l. \times 1000}{16,250,000} = \cdot 74l.$

Cost of water capable of utilisation per 1000 cubic metres $\Big\} \frac{11,050l. \times 1000}{13,750,000} = \cdot 80l.$

The reservoir will be completed in twelve months, and will be in full working order as soon as it is completed.

An occasional reservoir in a special locality may be more expensive than the above type reservoir, but if the number of sites are chosen, I think the figures given above will be found average ones.

This system of reservoirs is capable of great development. The Edku lake in Behera might be washed for some years and no sea water allowed to cover the lake in winter, with the result that it would be a reservoir capable of irrigating Lake Abukir and the low lands bordering Mareotis. Near the Nubarieh Canal there must be lands capable of storing water for summer use, while the Fayoum contains many valleys and depressions which might easily be converted into reservoirs."

Criticising these reservoirs in 1891, Colonel Ross wrote:—

"Mr. Willcocks proposes an extensive system of collecting water in winter into local small reservoirs in the low lands, called by him *basin reservoirs*, and utilising it

in the critical period of summer irrigation. He has not studied very closely the arrangements for bringing water into a reservoir, so as to store 12½ millions, but the cost of adapting the canals will not be great. There is practically no demand for water in the Delta from December 1st to January 15th, and even till January 31st, save for wheat in the higher lands, and clover. It is probable that out of a total of 50 millions per day passing Cairo, 15 millions pass out into the sea, or into the lakes.

Even with the abstraction of the water in December–February to fill the Nubian reservoirs, there need be no fear of scarcity of water in the Delta in the winter.

The only data we have to go on as regards these reservoirs are those of the Birket-el-Kadra lake, near Atfeh, from the stored water of which Alexandria used to be supplied in summer by the Mahmoudieh Canal. We do not know if the Alexandrians drank this water or merely used it for irrigation and navigation, but it seems almost certain that it must have been used for irrigation. The details are lacking.

Mr. Willcocks' reservoirs seem to me so shallow compared to the Birket-el-Kadra that there is a great danger of weeds growing. We have an instance of a lake near Damietta which remains full of weeds all the year round. Also many of the sluggish outfalls into Menzaleh are absolutely choked with weeds. These weeds are tall cane weeds, and their stalks must seriously reduce the capacity of the reservoir. In the cases where their are no weeds, the land is too salt for them to grow. I am therefore driven to the conclusion that the immediate result of freshening these shallow ponds will be to encourage a growth of weeds, which may eventually reduce the water contents by 50 per cent.

I should therefore recommend the deeper class of basin reservoir not less than 1·50 metre deep.

The typical reservoir given by Mr. Willcocks is about 3000 acres, irrigating 6000 acres dry crop or 4500 acres rice. Hence they may be assumed to take up ⅓ of the 1,200,000 salt waste lands. A great difficulty will arise in compensating the owners who are evicted to make the reservoir. The 'Birriyah' is not sufficiently known to enable any exact estimate to be framed of the extra cost.

As regards these reservoirs, I consider that they have yet to be tried. If they are successful they will be exceedingly useful in supplementing summer irrigation in the northern parts of the Delta, and will aid in land reclamation. An experiment might be tried in 1892 at a small cost."

The basin reservoirs as originally proposed in 1891 were to have had no masonry revetments, and to have been 1·00 metre deep. The reservoirs as now designed have masonry revetments, and are 1·30 metre deep.

We can now compare the cost of the water which can be utilised from the different reservoirs per 1000 cubic metres :—

	Cost per 1000 cubic metres
Assuân dam, at R.L. 107·00	£1·20
Wady Rayan reservoir	1·60
Basin reservoirs in the waste lands	·80

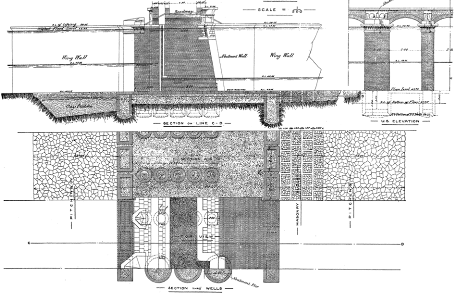
In order to put the perennial irrigation of Upper Egypt on a secure

ASSIOUT BARRAGE

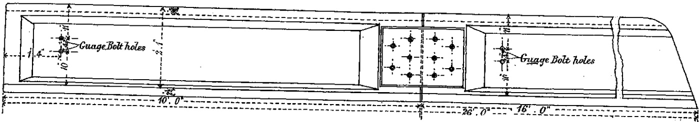
DESIGN WITH 120 OPENINGS of 5 Metres EACH

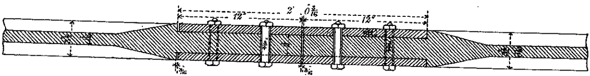
DETAILS

SCALE = 1/200



GENERAL PLAN OF PILE.



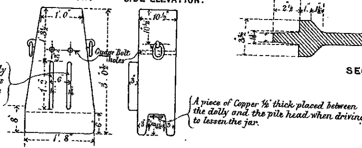


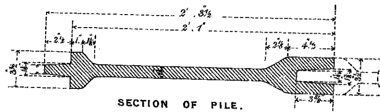
SECTION THROUGH JOINT.

Scales. ½" = 1 Foot & 1½" = 1 Foot

DOLLY.

REAR ELEVATION. SIDE ELEVATION.





SECTION OF PILE.

IRON SHEET PILES FOR ASSIOUT BARRAGE

footing, and enable this irrigation to take its share of the Assuân reservoir water, it was necessary to construct a barrage across the Nile downstream of the Ibrahimia Canal head at Assiout, and a regulator at the head of the canal. These works were designed at the same time as the reservoir projects and by the same staff. The Rayah Tewfiki head was taken as a type. Plate XLIV. gives a cross section of the proposed work. The work consists of 120 openings of 5 metres each, with 2-metres wide piers between. The superstructure and regulating apparatus are similar to those at the Delta Barrage, while the foundations are similar to those at the Rayah Tewfiki head. Now that the works have commenced, however, it has been decided to put down cast-iron sheet piling 8 metres long instead of the up and down stream wells, and to have a continuous floor of a uniform thickness of 3 metres, similar in every way to the existing Delta Barrage. The pile design on Plate XLIV.A was kindly given me by Sir Benjamin Baker. The lock will have a width of 16 metres, to pass the largest steamers on the Nile.

Adjoining the Assiout Barrage will be the regulating head and lock of the Ibrahimia Canal. The design of this work is exactly similar to that of the Rayah Tewfiki head. The canal head will have to hold up water in flood, which the Assiout Barrage will not be called upon to do.

The Assiout Barrage will not be used in flood, but will have a maximum depth of water of 10·20 metres. In summer, with a maximum depth of water of 4·60 metres on its upstream side, it may be called on to hold up 2·50 metres. The lock will be 80 metres by 16 metres. The Ibrahimia Canal head may be called on to work in flood. With a maximum depth of water of 9·50 metres on its upstream side, it may be called on to hold up 2·50 metres.

The estimated cost of the works is as follows :—

Assiout Barrage	£449,000
Ibrahimia canal head	£ 76,000
Total	£525,000

The details of the above sums are given in the following estimates of cost :—

Estimate of Cost of Assiout Barrage.

Regulator.

	cubic metres			
Foundation wells	36,000	at	£4	= £144,000
Rubble masonry	36,000	at	1	= 36,000
Ashlar	7,200	at	3	= 21,600
Brickwork	43,000	at	1·2	= 51,600
Pitching	45,000	at	·30	= 13,500

Puddle	25,000	at	£·20	=	£5,000
Earthwork	640,000	at	·05	=	32,000
Pumping				=	3,000
	square metres				
Regulating gates	2,700	at	£10	=	27,000
					£333,700
Contingencies at 10 per cent.					33,300
Total					£367,000

Lock.

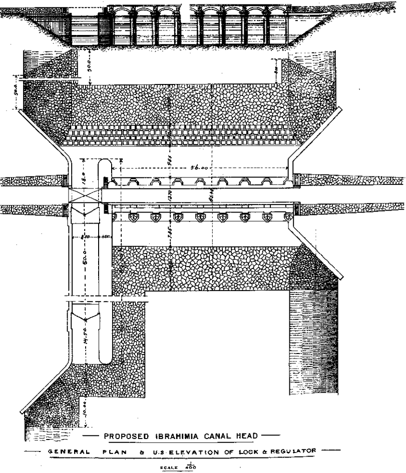
	cubic metres				
Foundation wells	9,000	at	£4	=	£36,000
Rubble masonry	3,500	at	1	=	3,500
Ashlar	1,100	at	4	=	4,400
Brickwork	11,000	at	1·2	=	13,200
Pitching	10,000	at	·3	=	3,000
Earthwork	230,000	at	·05	=	11,500
Pumping				=	1,000
	square metres				
Lock gates, drawbridge, &c.	80	at	25	=	2,000
					74,600
Contingencies at 10 per cent.					7,400
Total					£82,000

Regulator	£367,000
Lock	82,000
Total	£449,000

ESTIMATE OF COST OF IBRAHIMIA CANAL HEAD.

Regulator.

	cubic metres				
Foundation wells	3,800	at	£4	=	£15,200
Rubble masonry	2,900	at	1	=	2,900
Ashlar	500	at	3	=	1,500
Brickwork	4,500	at	1·2	=	5,400
Pitching	3,000	at	·30	=	900
Puddle	2,000	at	·20	=	400
Earthwork	40,000	at	·05	=	2,000
Pumping				=	1,000
	square metres				
Regulating gates	400	at	9	=	3,600
Total					£32,900
Contingencies at 10 per cent.					3,100
Grand total					£36,000



PROPOSED IBRAHIMIA CANAL HEAD

GENERAL PLAN & U.S. ELEVATION OF LOCK & REGULATOR

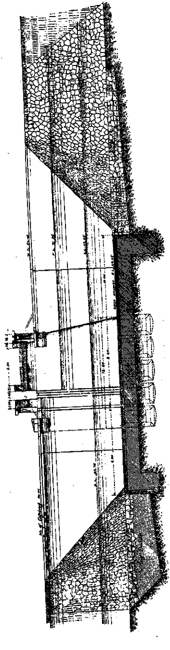
SCALE $\frac{1}{400}$

IBRAHIMIYAH CANAL HEAD-REG^R. ASSIOUT

DESIGN WITH 8 OPENINGS OF 5 METRES EACH

CROSS SECTION

SCALE = $\frac{1}{400}$



Lock.

	cubic metres				
Foundation wells	4,400	at	£4	=	£17,600
Rubble masonry	1,700	at	1	=	1,700
Ashlar	700	at	4	=	2,800
Brickwork	7,000	at	1·2	=	8,400
Pitching	2,000	at	·30	=	600
Earthwork	40,000	at	·05	=	2,000
Pumping				=	1,000
	square metres				
Lock gates, drawbridge, &c.	80	at	25	=	2,000
Total					£36,100
Contingencies at 10 per cent.					3,900
Grand total					£40,000

Regulator	£36,000
Lock	40,000
Total	£76,000

It was stated on pages 191 *and* 192, *that even in the lowest years the percolation during summer into either the Damietta or Rosetta Branch was* 23 *cubic metres per second or* 2,000,000 *per day.* It was moreover stated on page 427 that the critical period of summer irrigation lasted seventy-five days. The reserve of water in either of the two branches is therefore $75 \times 2{,}000{,}000 = 150{,}000{,}000$ cubic metres. As a Barrage at Samanud would cost 300,000*l.*, and enable this water to be utilised in the Garbia province, at present very badly off for water, it would certainly be worth the while of the Government to construct this work.

The cost of 1000 cubic metres of water capable of utilisation would be $\frac{300{,}000 \times 1000}{150{,}000{,}000} = 2l.$

This sum is not excessive when it is considered that the barrage would serve the double purpose of reservoir dam and barrage.

It might be interesting to note here the value of 1,000,000 *cubic metres of water in a year of very scarce summer supply.*

	cubic metres
An area of cotton needs 22 cubic metres per day for 75 days, or	1640
An area of rice needs 40 " "	3000
Say a mean of	2500

If we consider an acre of rice or cotton as worth only 3*l.* in the north of Egypt, even then the value of 1,000,000 cubic metres of water $= \frac{3 \times 1{,}000{,}000}{2{,}500} = 1200l.$ in a year of scarcity.

We have considered every reservoir which could be constructed in Egypt. We now look outside of Egypt.

Lake Tsana or Dembea, at the sources of the Blue Nile, would make an

excellent reservoir, since the Blue Nile has a steep and steady slope, and traverses no swamps. The water would course down to Egypt. The area of the lake is 3,000,000,000 square metres, the catchment basin 18,000,000,000 square metres, and the annual rainfall 1 metre. One-third the rainfall or 6,000,000,000 square metres could be stored by a dam 3 metres high. This water would be of the greatest value to the Sennaar Province and to Egypt.

Lakes Victoria and Albert at the sources of the White Nile have areas of 70,000,000,000 and 4,500,000,000 square metres. They would make excellent reservoirs, but the *Sadd region* between Bôr and the Sobat junction would have to be skilfully handled before the water could be assured at Khartoum. On page 28 is much interesting information about the discharges of the White Nile. If the Bahr el Gebel were taken in hand, and the Bahr el Ziraf and all the eastern branches of the river closed, and the river water forced to keep in one branch by gradually forming incipient banks from Bôr to the Saubat river by means of stuff dredged out of the Bahr el Gebel channel and immediately planted with willows, a steady improvement would soon take place. I now quote from my report on the "permanent removal of the Sadds in the White Nile."

"The willow is naturally an habitat of arctic regions and has gradually travelled southward. It is the great reclaimer of swamps. Now most of the great rivers of the earth flow either from north to south or from great mountain ranges under perpetual snow, and so gradually extend the willow from the cold and arctic regions to the swamps and plains of the temperate and tropic regions. The White Nile rises neither in the north nor in mountain ranges of perpetual snow, and the willow has had no opportunity of travelling down with the current. I have Dr. Schweinfurth's authority for stating that neither the White Nile nor the Gazelle River has any willows.

"Corthel, in his book on the 'Mississippi Jetties,' thus describes how willows act in the swamps to the north of New Orleans.

"'The seeds of grasses, flags and reeds that came down with the river found a lodgment on the half-submerged banks and soon covered them with a rank vegetation. This growth caught the sediment carried into it by the overflowing waters and built up the banks still higher, on which sprang up a *dense growth of willows, crowding out the weaker vegetation and taking possession of the whole district.*'

"By planting rows of willow cuttings like spurs 250 metres apart from the left bank to deep water, along the White Nile from Fashoda to Abba, it might be possible to thoroughly train the White Nile in this unhealthy region and reclaim the whole of the foreshore.

"Willows have the power over every other tree of feeding upon and gradually exterminating all unwholesome matters in the waters in which they grow, and their thorough introduction into these regions would purify the unhealthy waters of this branch of the Nile."

If by the means indicated above, a channel could be found for the waters of the White Nile and the Gazelle river, the reservoir question would be definitely settled for Egypt.

APPENDIX I.

DESCRIPTION AND STRENGTH OF EGYPTIAN STONES, AND STRENGTH OF EGYPTIAN MORTARS.

DESCRIPTION AND STRENGTH OF EGYPTIAN STONES.

The building stones in Egypt are syenite, Nubian sandstone, and limestone of the tertiary formation. Specimens of the different classes of stone were sent to Professor Hudson Beare, of University College, London, to be tested, and the following is an epitome of his report. His calculations were all made in pounds and square inches, and I have reduced them to kilogrammes and square centimetres.

1 lb. per square inch = ·07 kilogrammes per square centimetre.

1 kilogramme per square centimetre = 14·2 lbs. per square inch.

Class of Stone	Weight of a cubic meter in kilogrammes	Crushing Load in kilogrammes per square centimetre	Absorption of Water per cent. of Dry Weight	Remarks
Limestone from Old Cairo.	2560 2560 2580 2590 2590 2760	1045 801 1121 1051 1068 1245	·80 1·09 1·27 ·73 .. ·75	All except the fifth were 2½-inch cubes. The fifth was a 3-inch cube. The second specimen had crystalline hollow spaces in interior.
	2610	1056	·93	Mean of 18 cubes.
Limestone from the Tura quarries.	2310 2330 2340 2430 2490	367 523 589 566 708	4·27 4·35 4·02 2·36 1·40	All 2½-inch cubes.
	2380	551	3·28	Mean of 15 cubes.

TABLE—*continued.*

Class of Stone	Weight of a cubic metre in kilo-grammes	Crushing Load in kilo-grammes per square centimetre	Absorption of Water per cent. of Dry Weight	Remarks
Black diorite	2790 2810	1279 1348	·25 ·12	All 2-inch cubes.
	2800	1313	·19	Mean of 5 cubes.
Red syenite	2640 2640	1307 1530	·13 ·26	All 2-inch cubes.
	2640	1418	·20	Mean of 6 cubes.
Nubian sandstone	1850 1860 1890 1950	152 112 202 264	11·16 9·91 10·32 9·87	All 2½-inch cubes.
	1880	183	10·31	Mean of 12 cubes.

Limestone from Old Cairo.—This is a dense crystalline stone, slatey grey, greyish white and creamy in colour; the greyish white was the densest and strongest.

Limestone from Tura.—This is a semi-crystalline stone, not dense, creamy in colour; the denser the stone the stronger.

Black Diorite from Assuân.—A micaceous diorite with rather fine crystals.

Red Syenite from Assuân.—A granite with large pink flat crystals of felspar.

Nubian Sandstone.—This is a coarse silicious sandstone, with little cementing material, of a whitish colour. The denser the stronger.

From each block of Old Cairo and Tura limestone and Nubian sandstone nine cubes were sawn out, and the bed faces of each cube rubbed smooth and parallel. These were all 2½-inch cubes, except from one block from Old Cairo, which had sides of 3 inches.

From the syenite and diorite blocks rough pieces were cut out by chisels and wedges and dressed to size by chisels, and then finally rubbed down to 2-inch cubes.

The following tests were made: density, absorption of water, crushing strength.

Density and Weight.—Each specimen after thorough drying was carefully weighed, its volume calculated, and therefrom its density.

Absorption of Water.—Two specimens of each block were, after weighing, immersed in distilled water at air temperature, and kept there for seven days. They were then taken out, at once wiped dry and reweighed. The gain of weight represents the water absorbed.

Crushing Strength.—The bed faces of the cubes were strickled over with a thin layer of plaster of Paris; these were then rubbed quite smooth and parallel, and in testing, these faces were applied directly to the dies of the machine. All the cubes were tested when quite dry. The load was gradually increased from zero to crushing load; if any cracking occurred at lower loads than the actual breaking load, the fact was noted.

Old Cairo Limestone.—The heaviest block had the greatest crushing strength. The cubes began to crack at loads which were 50 per cent. of the crushing loads, differing very much in this respect from the granites. The water absorbed was small but distinct.

Tura Limestone.—The densities vary from 2·31 to 2·49, and the crushing strength from 367 to 708 kilogrammes per square centimetre. The denser the stone the stronger. The densest stone approaches those from Old Cairo. The greater the density the less the water absorbed. The cracking load is not much under the breaking load.

Black Diorite from Assuân. Red Syenite from Assuân.—The syenite is less dense than the diorite, but it is distinctly the stronger stone. These granites are practically non-absorbent. The dampness of surface causes the trifling additional weight.

The cracking and crushing load is one.

The diorite is very difficult to work and refuses to split at the wedge lines. The syenite is easy to work and splits along the wedge lines.

Nubian Sandstone.—The denser blocks are *much* stronger than the less dense. The cracking and crushing weight is one. This stone is exceptionally poor, and absorbs an extraordinary quantity of water. The stone is more like an English oolite than a sandstone. A series of 4-inch cubes when crushed gave a compressive strength over 50 per cent. in excess of the 2½-inch cubes.

The coefficients of elasticity of Old Cairo and Tura limestone are 500,000 and 350,000 kilogrammes per square centimetre respectively—the same as hard English dolomites.

STRENGTH OF EGYPTIAN MORTARS.

In order to test the strength of the hydraulic mortars of Egypt, a continuous series of tensile and compressive experiments has been made. The tensile tests were made with briquettes of a minimum section of 1 square inch, while the cubes which were crushed had a side of 5 centimetres. The crushing machine was not a delicate one and needed frequent adjustments; these adjustments were often the cause of the cubes being broken quite independently of any weakness in the mortar. We also found it was difficult to get the two surfaces which touched the crushing boards perfectly smooth and parallel to each other. Taking the above into consideration, I have been able to place little reliance on the compressive experiments, and have preferred multiplying the tensile strength by 10, and considering the results as the compressive strengths.

The limes tested were the following :—

Fat *Cairo* lime from the Bata el Bakkar quarry.

Fat *Silsila* lime from the Raghama quarry, of a *white* colour.

Fat *Silsila* lime from the Raghama and Fatèra, of a *dark* colour.

The limestone was burnt and slaked, and then used fresh. The puzzuolana was made from rich black Nile deposit, burnt to a dark red colour, and then ground and sifted. It was likewise used fresh. The sand was quartz sand from the desert. The puzzuolana classed as coarse was sifted through a sieve of 400 meshes to the square inch, and that called fine was sifted through a sieve of 900 meshes to the inch. The coarse sand passed through a sieve of 400 meshes to the inch, but was retained on a sieve of 900 meshes to the inch. The fine sand was sifted through a sieve of 900 meshes to the inch.

The slaked lime and puzzuolana were mixed dry in the proper proportions and then had water added to them. A portion was taken from the mass, stirred in a mixer for two hours, and then made into briquettes. The briquettes were left in the moulds for twenty-four hours, then put into damp sand for six days, and finally into water for six months less a week. At the end of six months from the day of moulding they were broken. The mass of the mortar was put into metal troughs and kept wet, and briquettes were made daily from it till it was expended. In some cases eighteen days elapsed between the making of the mortar and the moulding of the briquettes.

Twelve briquettes were always made; six were broken after six months, and the rest will be broken when twelve months have elapsed. So far we have broken after twelve months none of the briquettes made of the good proportions and good ingredients mentioned in the table; but judging from the results with the inferior mixtures, we may fairly anticipate a gain of 50 per cent. in the strength of the mortars after twelve months as compared to the six months tests.

The best proportions for the ingredients have been found to be as follows :—

1 part by measure of slaked fat lime.

1½ part by measure of fine puzzuolana.

1 part by measure of coarse desert sand.

By way of comparison, briquettes and cubes were made of the well known Theil lime from France, of which especially good specimen bags were ordered. This lime is so well known and appreciated, that the comparative tests prove conclusively that in Egypt we have the materials for manufacturing a really first-class hydraulic mortar.

Hydraulic mortar made of the Cairo lime is stronger if used ten days after manufacture than if it is used fresh. Both the Silsila lime mortars are distinctly stronger, however, if used fresh than if they are allowed to stand even for twenty-four hours. These latter mortars decrease in strength steadily as they get older.

Briquettes and cubes were also made of mixtures of 4 lime, 8 sand and 1 cement, and 10 lime, 5 sand and 1 cement. These were the proportions of the mortars used at the new Puentes and Villar dams in Spain (mentioned in Appendix I. of the Report of 1894). It is very evident from the tests recorded at the bottom of the table that the Egyptian limestones are not at all suited for mortars made of these ingredients.

Finally, briquettes were made of finely pounded unburnt clay, sifted through sieves of 5,000 meshes to the inch, and mixed with lime and sand, or a lime alone. The best proportion was 2 lime, 1 sand and 1 unburnt clay, but the tests recorded at the bottom of the table prove that the use of unburnt clay is attended with risks, and results in a mortar of mediocre strength.

Rubble masonry at the dams could be constructed with puzzuolana mortar at a rate of 45 paistres per cubic metre, while in the estimates I have entered 80 piastres, 100 piastres and 150 piastres per cubic metre, according to the proportion of the face work which is to be built of cement mortar. The rates allowed are accordingly excessively liberal.

TENSILE STRENGTH OF MORTARS IN KILOGRAMMES PER SQUARE CENTIMETRE.

Briquettes Tested Six Months after Manufacture.

(Multiply by 14·2 to obtain lbs. per square inch.)

Age of Mortar in days	Neat Theil Lime from France	1 Theil Lime, 3 Coarse Sand	1 Theil Lime, 3 Fine sand	1 Cairo Lime, 1½ Puzzuolana, Fine	1 Cairo Lime, 1½ Puzzuolana, coarse	1 Cairo Lime, 1½ Puzzuolana, Fine, 1 Fine Sand	1 Dark Silsila Lime, 1½ Puzzuolana, Fine	1 Dark Silsila Lime, 1½ Puzzuolana, Coarse	1 Dark Silsila Lime, 1½ Puzzuolana, Fine, 1 Coarse Sand	1 White Silsila Lime, 1½ Puzzuolana, Fine	1 White Silsila Lime, 1½ Puzzuolana, Fine, 1 Fine Sand
fresh	24	16	8	15	16	16	21	20	14	20	18
1	..	..	..	14	16	18	19	14	12	14	16
2	..	..	..	12	19	17	17	14	9	12	13
3	..	..	..	17	17	21	15	14	9	16	14
4	..	..	..	15	17	19	16	12	11	17	14
5	..	..	..	15	17	17	17	12	12	16	14
6	..	..	..	12	17	17	19	..	12	15	13
7	..	..	..	12	15	17	18	..	..	18	13
8	..	..	..	15	14	20	13	..	..	15	13
9	..	..	..	15	16	20	11	..	..	12	12
10	..	..	..	16	17	23	11	..	..	12	12
11	..	..	..	..	..	..	12	..	..	14	12
12	..	..	..	..	..	..	14	..	..	16	11
13	..	..	..	..	..	..	12	..	..	14	..
14	..	..	..	..	..	..	11	..	..	15	..
15	..	..	..	..	..	..	11	..	..	13	..
16	..	..	..	..	..	..	12	..	..	12	..
17	..	..	..	..	..	..	12	..	..	14	..
18	..	..	..	..	..	..	12	..	..	..	..

Briquettes of 10 lime, 1 cement and 5 sand were broken at 8 kilos. per square centimetre.
" 4 " 1 " 8 " " 7 " "
" 2 " 1 sand and 1 unburnt stiff clay were broken at 10 kilos. per sq. centim.

In the case of the last briquettes, the mortar had to be put into the moulds immediately after it was made, as the least delay resulted in the briquettes either cracking or melting away when placed in water.

APPENDIX II.

A NOTE BY DR. SCHWEINFURTH ON THE SALT IN THE WADY RAYAN.

APPEARED ORIGINALLY AS APPENDIX XIII. IN 'PERENNIAL IRRIGATION AND FLOOD PROTECTION.' THE EGYPTIAN GOVERNMENT, 1894.

REPORT ON THE SALT* IN THE WADY RAYAN RESERVOIR.

BY G. SCHWEINFURTH.

An exact valuation of the amount of salt which will be contained in this reservoir, when the water has risen to a height of 27 metres above the Mediterranean, cannot be made, owing to the absence of information on some of the following points :—

Data wanting

1. The percentage of salt in the soil of the reservoir bed.
2. The thickness of the salty strata of the bed permeable to water.
3. Mean specific gravity of the desert soil of the reservoir and the feeder canal.
4. The time of filling.
5. The dimensions of the canal and the area of the lands flooded by the canal.
6. The percentage of salt in the desert soil traversed by the canal, and the extent of the inundation.
7. The thickness of the strata permeable to water in the bed and sides of the canal.
8. The percentage of salt in the Nile deposits traversed by the canal in the Nile valley.
9. The thickness of the strata permeable to water in this last canal.
10. The mean specific gravity of the Nile deposits traversed by the canal.
11. The volume of subsoil water which will enter the canal by infiltration, and the percentage of salt in it.

To find an approximate value we can, however, substitute for the exact data approximate ones, based on observed facts and obtained tentatively.

Numbers 4 and 5 are of the greatest importance in your present inquiry. I shall show further on that if the filling lasts seven years, it will in no way compromise either the Nile or the cultivation, but if the filling is slow the water of the resorvoir will be unfit for irrigation.

* By "salt" I always mean "Chlorure of Sodium."

Agricultural axioms.—Once salt is contained in the water of the reservoir, there it will remain for ever unless there is outflow. This is a fundamental truth in Egyptian agriculture, which is nothing but a continued fight against salt. If there is no outflow, the constant entry of Nile water can in no way remedy this state of affairs, and the salt will accumulate owing to evaporation all the years that the reservoir is being filled.

Salt is unalterable.—Salt (chlorure of sodium) undergoes no chemical transformation in contact with Nile water, or with any of the substances the water contains in suspension or solution. One other peculiarity of the salt is the invariableness of its degree of solubility under different temperatures.

Earth and rock specimens should be analysed.—To obtain the percentage and specific gravity of the salts contained in the desert soils in the reservoir a special inquiry should be instituted.

A large and varied number of specimens should be analysed chemically to find the mean quantity of the salt.

The surface of the Wady Rayan, as compared to other parts of the desert, contains a large quantity of salt, because the rainfall finds no escape from the depression, and concentrates there the salt of the adjacent lands. The efflorescence, also, which is always more active where the ground is alternatively wet and dry, tends to augment the quantity of salt at the bottoms of depressions which have no outlet. During my visit in 1884 I myself saw quantities of salt at the surface of the ground in the Wady Rayan. There is a single spring of sweet water, but it becomes brackish after flowing a short distance, and gives birth to scarcely any vegetation.

Limits of cultivation in salted lands.—In Egypt it has been found by observation that certain wild and cultivated plants can support 2 per cent. of salt in the soil, provided that the latter is perpetually humid. Under these conditions of perpetual humidity the salt may rise to 4 per cent. before rendering the soil absolutely sterile. On the contrary, a soil which is alternately wet and dry is rendered sterile by 1 per cent. of salt.

Almost all the desert soils of the tertiary formation in the interior of Egypt are naturally uncultivable without washing and draining. It is for the same reason that they are generally devoid of wild plants.

Natural drainage in the desert.—The *high limestone plateaus* of the eastern desert above 1000 metres in height, the Mediterranean *littoral*, and the *beds* of all torrents, are an exception. These lands have lost the salt which is contained in all limestone strata in clay strata, and on the desert plains. The more abundant winter rains in the two first instances, and in the case of the third the concentrated drainage of the rare falls of rain, have produced this result.

The maximum percentage of salt possible in the desert soils.—In accordance with these facts one may roughly estimate, without fear of exaggeration, the maximum quantity of salt in the desert soil as 2 per cent. I shall use this figure in my calculations, and I am confident it will never be surpassed by the result of the analysis proposed by me.

The thickness of the stratum accessible to the dissolving action of the water may be taken as 20 centimetres at the bottom of the Wady Rayan, and as 50 centimetres for the bed and sides of the canal, and the inundated lands which will be more thoroughly washed and undermined by the waves.

Categories of desert soils.—One can distinguish three categories of desert soils of tertiary origin as far as their permeability is concerned, and also as to the ease with which the salt they contain can be dissolved.

1. Solid rocks; beds of limestone, of silicious and argillaceous limestone, and of calcareous sandstone.

2. Loose soils, composed of decomposed rocks, pebbles, boulders, shingle, etc.

3. Marly clays and sands, in layers overlying the plains, in the undulating slopes of the hills, and at the feet of bluffs.

To arrive methodically at the mean percentage of salt, it becomes necessary to make a quantitative chemical analysis of each of the three categories of soil separately, then measure their specific gravity, discover the thickness of the stratum which is permeable, and finally fix on the area. These are the necessary elements. The calculation which follows has no pretence to such precision.

Data more or less exact.—The following are the established or approximate facts which are at my disposal:—

1. Dimensions of the canal traversing the desert:—

Length	25 kilometres.
Breadth	40 metres.
Depth of water	9 metres.

2. Time of filling probably seven years.

3. Volume of water contained in the reservoir below R.L. + 27 metres = 18,600 millions of cubic metres.

4. Superficies of the water at R.L. 27 . . . 650 millions of square metres.

5. Annual evaporation . . . 2 metres.

6. Salt contained in Nile water after Professor Sickenberger's analysis in 1883, 40 milligrammes per litre = 40 grammes per metre cube = $\frac{1}{250}$ per cent.*

(The Nile in summer has only $\frac{1}{2000}$ per cent. of salt).

7. The mean specific gravity of salt, 2·25.

8. Solubility of salt water, 1 : 2·75.

9. The specific gravity of the mean desert soils has been taken as practically the same as that of salt.

Estimate of salt in the Wady Rayan reservoir.—The different sources from which salt can enter the proposed reservoir are enumerated in the following list:—

	Salt in the reservoir in millions of grammes
1. From the Nile in flood when the reservoir is full: 18,600 millions × 40 . . . . =	744,000
2. From the Nile in flood, to make good the losses from evaporation in seven years: 3000 millions of cubic metres × 40 . . . . =	120,000
3. The losses by evaporation in the canals during seven years =	36,000
4. From the lands in the bed of the reservoir: 650 millions square metres × by 0^m 2 = 130 millions cubic metres (130,000,000 × 2·25) = 290 billions of grammes, of which 2 per cent. amount to . . . . . . =	5,800,000

* According to Sickenberger, ordinary well water in Egypt, which is used for irrigation, contains $\frac{1}{15}$ per cent. of salt.

		Salt in the reservoir in millions of grammes
5. From the bed and banks of the canal in the desert and the inundations: 2 per cent. of salt in a belt of 50 centimetres	=	650,000
6. From the Nile deposits composing the bed and banks of the canal in the Nile valley, 20 kilometres long.		
7. From infiltrations and drainage into the same canal	=	150,000
Total		7,500,000

This equals 7,500,000 millions of grammes or, 0·04 per cent.

The reservoir would therefore contain 7500 millions of kilogrammes of salt, or $\frac{1}{25}$ per cent. of salt; that is to say, half of the salt which exists in the water of those wells in Egypt which can be used for purposes of irrigation.

Substitution of exact for approximation data.—Water containing a similar proportion of salt could be turned into the Nile without in any way compromising the agriculture. I again report that my calculation is based on maximum and assumed data. To obtain an exact calculation we must obtain exact data.

The phenomenon of sweet water in the Qurun lake.—I conclude by calling attention to the extraordinary phenomenon of the water of Lake Qurun in the Fayûm being nearly sweet, in spite of the fact that it is the residuum of the ancient Lake Mœris. This question is intimately connected with that of the Wady Rayan reservoir. Very probably the creation of the depression of the Fayûm, and the subsidence of the strata composing its bed, were due to the same geological action which produced the Wady Rayan. This reflection makes it probable that this latter reservoir, when it is full, will disclose the same clefts and fissures in its bottom which I shall try and prove exist in the bed of the Qurun lake.

The great probability of subterranean drainage from the Wady Rayan.—These subterranean passages will cause the loss of a great part of the water stored in the reservoir, and will give birth to distant springs, and probably even to the formation of new oases in the Libyan desert. The effect on the reservoir will be the following: the quantity of salt in the reservoir will be diminished, but the work of filling the reservoir will be more difficult and longer in operation.

The Qurun lake has to-day a surface of about 250 millions of square metres, and probably a cubic content of 1500 millions of cubic metres.

If we suppose that the lake has existed at this same level since the Roman period (A.D. 200), the lake would have received salt from the Nile since that period.

The salt contained in the Fayûm lake:—

		In millions of grammes
1. Salt in the entire mass of water, 1500 × 40	=	60,000
2. Salt contained in the strata of water evaporated annually during seventeen centuries, 2 × 250 × 40 × 1700	=	34,000,000
Total		34,060,000

The salt in this case would amount to 34,060 millions of kilogrammes, i.e. 2·27 per cent.

As, however, at the time in question, the lake had very probably its water level at + 0, its volume has decreased by 43 metres in perpendicular height during the seventeen centuries. We must therefore find the quantity of salt in the water which

was in excess of the present volume of the lake, and the annual loss by evaporation of the excess of the surface of the lake over the area of to-day. This latter excess equalled, in all probability, the present area of the lake.

At R.L.o the area of the lake was approximately 500 millions of square metres, and its excess volume was from thirteen to fourteen times the actual volume of to-day. I estimate this excess volume at 20,000 millions of cubic metres, and the salt at 800,000 millions of grammes. The diminution of the surface of the lake was slightly under 250,000 square metres per annum. The salt contained in the strata of water evaporated outside of the actual area of the lake to-day amounted in seventeen centuries to 17 billions of grammes. This total quantity of 17,800,000 millions of grammes of salt in 1500 millions of cubic metres of water gives a percentage of 1·186.

If we add 1·186 to 2·27 found before, we have 3·45 per cent. of salt in the lake to-day if it had existed only 1700 years, and at the beginning of that time, had been at level of the Mediterranean.

Other sources of salt in the lake hitherto omitted.—So far I have not considered the supply of salt from other sources, such as—

1. The infiltration water brought into the lake by the canal, and drains from the cultivated land of the Fayûm.

2. The greater quantity of salt in the Bahr Yusuf on entering the Fayûm, than in the Nile itself.

On the other hand, I have exaggerated in giving for the whole year the percentage of salt which is in the Nile only during flood.

Any way, one will readily see to what degree of concentration the salt ought to increase in a lake whose volume has been so considerably reduced through incalculable centuries. The vestige of the ancient water surface which are to be found to the north of the lake at a distance of 8 kilometres from its present edge near the temple, discovered by me in 1884, and the other incontrovertible proofs of the existence of a Mœris in the sense of Herodotis, make it very probable that its level rose in ancient times to a level of 22 or 23 metres above the Mediterranean.

The quantity of salt derived from Mœris.—According to Major Brown, the ancient Mœris had a surface of 1600 millions of square metres. Its volume may be calculated at 30,000 millions of cubic metres. This volume, reduced to 1500 millions cubic metres, brings the percentage of salt in the water of the actual lake to ·8 per cent. by itself, and the salt contained in the stratum evaporated during a single year being 120,000 millions of grammes, ought in ten centuries to amount to 128,000 millions of kilogrammes. This would represent in the 1500 millions of cubic metres, of the lake of to-day, a percentage of 8·53.

8·5 per cent. of salt at least has disappeared in the Fayûm lake.—But who knows since when the great lake existed, and how many centuries elapsed before the controlling of its water was begun? What has become of the salt which would have mounted to figures far higher than mine? Where, again, are the salts contained in the basin before the Nile water entered, and the salt of infiltration from drainage and irrigation? The salt in the lake to-day bears no relation to the quantities I have enumerated.

To-day the waters of the Qurun lake are but slightly brackish. They are even potable, and inhabited by fresh-water fish from the Nile. It has been definitely

proved that lake Mœris never had a natural outlet towards the interior of the country, and that it never even was in connection with the Wady Rayan, which it nearly touched. (See Major Brown's work on the Fayûm, pages 43 and 48). The Fayûm basin is closed on all sides by bluffs and hills of considerable height. We have seen that, in spite of their concentration through immemorial ages, the salt in the waters of the lake has not increased. This renewal of fresh water can only be accounted for by subterranean drainage. Where have the waters gone to?

(Lake Tchad, in the central Soudan, is an example of subterranean drainage on a larger scale. The waters are perfectly sweet, in spite of the absence of any apparent outlet. The lake is drained by active infiltrations towards the N.E., in low depressions which are known as the Bahr el Gazal.)

The Natron lakes are probably due to direct infiltrations from the Nile, since Sickenberger in 1892 observed that all the springs which gave birth to the lakes were situated on the eastern side of the valley. The difference of level, also, prevents the establishment of any similarity between the systems, as well as the fact that the springs of the Natron lakes are not thermal.

Oases and depressions provided with springs are to be found to the north-west of the Fayûm as far as Siwah; and this latter oasis may perhaps obtain some of its water from the Qurun lake in spite of the difference of levels. There are many phenomena connected with thermal springs which as yet await solution. We are still in ignorance of the destination of the currents of those thermal springs which traverse the bottom of the depression of the great oases and the oasis of Dakhel, at great depths. These springs are abundant, and flow evidently towards the north. It is probable that all these subterranean streams, which are fed by the Nile, flow towards the Marmarica coast between Alexandria and Derna. There, owing to the tensile force inherent in all water at a high temperature, they are discharged at great depths below the level of the Mediterranean Sea.

(*Signed*) G. SCHWEINFURTH.

APPENDIX III.

NOTE ON IRRIGATION AND DRAINAGE, BEHÊRA PROVINCE.

BY MR. N. E. VERSCHOYLE, INSPECTOR OF IRRIGATION.

IRRIGATION.

THE province of Behêra contains some 700,000 acres of culturable land of very varying quality, the chief factor affecting the latter being its elevation.

The northern portion of the province lies so low, that minute differences in elevation have marked effects in the quality of the soil.

The province derives its water supply from the Rayah Behêra Canal, taking off on the west of the Rosetta branch above the Barrage.

During the flood season the Rayah Behêra is supplied through the Khatatbah feeder, situated 40 kilometres below the Barrage.

The result of this practice is to diminish the silt deposit in the upper reaches of the canal, and to relieve its sandy slopes from the erosive action of the flood supply. During flood a further supply is also drawn in by the Mahmoudia and Rosetta Canals, whose heads are some 150 kilometres below the Barrage.

The Rayah Behêra and its continuations, the Khatatbah and Sahel Markaz Canals, run down the eastern limit of the province for 147 kilometres to Atf, where they tail into the Mahmoudia Canal, the principal irrigation and navigation channel of the province. The Mahmoudia Canal is fed at its head through the Sahel Markaz, also during flood time directly from the river through the head locks, and again at kilometre 15 through the Khandaq Sherki Canal. The Rayah Behêra, Khatatbah and Sahel Markaz form one system. At 80 kilometres from the Rayah Behêra head comes the Kafr Bulin regulator, above which take off the Nubaria and Abu Dyab Canals, each of which, with its branches, form a system. Thirteen kilometres below Kafr Bulin on the Khatatbah Canal comes the Kafr Eis regulator, where take off the Khandaq Canals, which run north-west along the Cairo-Alexandria Railway, finally uniting and forming the main feeder of the Mahmoudia Canal; and the West Ghannabia, tailing into the Daheri Canal, which latter channel has a head in the Khatatbah 14 kilometres below Kafr Eis. The Khandaq Canals, the West Ghannabia and the Daheri form systems 4 and 5. The sixth system is formed by the Mahmoudia Canal. The following table gives the chief details of the systems described above.

At the head of the Mahmoudia Canal there is a pumping station on the river which formerly raised the whole supply of the canal, and is now occasionally used for short periods in years of bad supply. The installation of pumps consists of eight

scoop-wheels 10 metres in diameter, and 3·00 to 3·60 metres in width, driven by two compound engines of 400 horse-power each, and four beam engines of 220 horse-power each. The eight wheels can lift from 23 cubic metres to 29 cubic metres per second, according to the lift, which varies from 2·20 to 2·70 metres.

CANAL SYSTEMS, BEHÊRA PROVINCE.

Name of System	Area Commanded	Length of Canal			Discharges, cubic metres per second	
		Main	Minor	Total	Maximum	Minimum
Rayah Behêra and Khatatbah	89,607	147·0	78·0	147·0	200	78
Nubaria	199,325	81·0	156·0	237·0	38	10
Abu Dyab	78,540	75·0	84·0	159·0	15	5
Khandaqs	75,805	77·0	124·0	201·0	55	26
West Ghannabia and Daheri	47,243	36·0	30·0	66·0	17	7
Mahmoudia	260,840	76·0	243·0	319·0	58	35
Totals	751,360	492·0	715·0	1207·0	..	..

Irrigation Programme.—Irrigation for the summer crops of cotton, rice, Indian corn and sugar, commences in April and is supposed to end with July. The seasons of course overlap, irrigation for the summer and flood crops being carried on at the same time. During April, May and June, the supply of water varies from 78 cubic metres to 81 cubic metres per second, and reaches 110 cubic metres by the end of July. The demand begins to exceed the supply in May, but does not become intense till July. To ensure as fair a distribution of water as possible, rotations, or the restriction of water supply to fixed periods to each irrigation sluice or lifting machine, are enforced generally from the middle of May till middle of August. The periods of supply and stoppage during rotations vary on the different canals, according to their length and whether rice is cultivated on them or not.

The following are the different periods of supply and stoppage in general use, the channels being as a rule divided into two sections.

The periods shown in systems *c* and *d* in the following table are enforced when owing to the intensity of demand it becomes necessary to subdivide the periods shown in systems *a* and *b*. The area under summer crops is from 220,000 to 240,000 acres. Assuming a consumption of 40 cubic metres per day for each acre of rice, the duty for the other summer crops is about 30 cubic metres. As a matter of fact, rice takes all the water that it can get up to 100 cubic metres per acre per day or more.

During flood, the discharge entering the province varies from 150 cubic metres to 210 cubic metres per second. A good deal of the latter is escaped.

After flood supplies have been run in all the channels for about a month, the system of running high and low supplies for alternate periods is commenced, and

continued until the introduction of regular summer rotations. The object of this restriction of supply is to prevent excessive irrigation, as the native cultivator rarely thinks of reducing his consumption, whether necessary or not, particularly if the water can be passed on to a drain. The introduction of this system during the past few years has been very beneficial.

PERIODS OF WATER SUPPLY AND STOPPAGE DURING SUMMER ROTATIONS.

System	Upper Section		Lower Section	
	Period of Supply, in days	Period of Stoppage, in days	Period of Supply, in days	Period of Stoppage, in days
a	8	10	9	9
b	4	5	4	5
c	4	14	5	13
d	3	6	3	6

The areas under flood crops of Indian corn and sabaim rice is about 110,000 acres.

Sowings for the winter crops of wheat, barley, beans, clover and onions also commence during flood time. Their area is about 300,000 acres. The discharge consumed is slightly less than during the summer. The northern portion of the province gets a rainfall of 200 to 250 millimetres during the winter months.

DRAINAGE.

For purposes of drainage, the province is divided into two systems—the eastern system which discharges into Lake Edku, where it is disposed of by evaporation during the spring and summer, and in the autumn and winter overflows into the sea; and the western or Mariotis system discharging into Lake Mariotis, from where, as soon as evaporation is unable to balance the discharge, it is pumped into the sea. 200,000*l.* have been spent during the past two years in remodelling and extending the drainage system of the province, which was quite inadequate. Owing to lack of funds for construction or maintenance, the channels had been made of utterly inadequate section and had, moreover, been allowed to choke badly. Another 230,000*l.* at least is required still to provide a fairly complete system of drains.

Immediate results have followed the expenditure of 1897 and 1898, land untouched before coming under cultivation, and cotton replacing rice. The following table gives the leading details of the two systems.

A main drain discharges directly into the lake, a secondary drain into a main drain, and a tertiary into a secondary drain.

DRAINAGE SYSTEMS, BEHÊRA PROVINCE.

Name of System	Area served, acres	Length of Channel				Aggregate Bed Widths of Outfalls, metres
		Primary, kilometres	Secondary, kilometres	Tertiary, kilometres	Total, kilometres	
Edku	383,148	82·00	107·90	94·40	284·30	43·00
Mariotis	379,085	105·20	121·50	47·20	273·90	42·00

It must be borne in mind that, owing to the small depths, the aggregate bed widths above only mean a sectional area of water way of about 54 square metres. The sectional area at head of Rayah Behêra in August is 205 square metres with a velocity 1·0 per second, while the sectional area at Khatatbah in flood is over 300 square metres. Part of the discharge due to the latter area escapes back to the river by the canal escapes. It will, however, be evident from the above that the drainage outfalls require enlargement.

The installation of pumps at Mex, which serve to keep down the level of the Lake Mariotis for six months of the year, will, when the work now in progress is completed, consist of the following pumps and engines :—

Pumps	Engines	Daily Discharge for Average Lift of 3 metres
		cubic metres
Two Gwynne's Invincible centrifugal pumps, horizontal shafts, 48" pipes.	Two horizontal compound engines, each 170 I.H.P., with surface condensers.	500,000
Five Farcot's pumps, centrifugal, with vertical shafts. Discharge pipes 5·0" to 8·4" diameter.	Two horizontal engines, each 350 I.H.P., with jet condensers and Corliss valves.	2,500,000
Total discharge per day		3,000,000
or 35 cubic metres per second.		

The following table gives the quantities pumped during the last four seasons and the expenditure incurred.

The cost of pumping per million cubic metres may be taken as 27*l.*, there being hardly any difference between the Gwynne's and Farcot's in this respect. The figures in column 3 of following table do not agree with this statement, because, up to date, the Gwynne's pumps have been run by a contract under which the cost of

pumping one million cubic metres came to 51*l.* It is evident from the figures for actual cost of pumping given above, that a large annual saving will be effected by working all the pumps directly by Government, as has been done in the case of the Farcot's pumps. The cost given per million pumped is that obtained with best Cardiff coal, costing 1·032*l.* per ton delivered at pumping station, which is a favourable rate.

MEX PUMPING STATION.

Season	Quantity Pumped, in cubic metres	Expenditure Incurred
1894–95	88,747,236	£4,605
1895–96	175,078,166	7,838
1896–97	216,994,810	8,068
1897–98	227,431,000	8,861

The question of drainage in the province is rendered a difficult one, owing to the low level of the ground to be drained with reference to the sea.

The lakes which serve as outfalls are very shallow. Drains with great bed-widths, small depths and slight gradients are obligatory. The first cost of the channels is therefore heavy, and what is worse their maintenance is costly, the shallow channels with mere dribbles of water in them for a considerable portion of the year being very liable to choke with weeds. These difficulties as regards construction are being faced. The future of the agriculture of the province depends largely on the liberality shown in alloting funds for the proper maintenance of the fine series of drains now being made.

N. E. VERSCHOYLE.

October 1898.

APPENDIX IV.

Assuân Gauge.

Pics and kirats converted into metres, referred to zero at R.L. 85·00 metres, or 1 pic 14 kirats

Kirats	Pic 0	Pic 1	Pic 2	Pic 3	Pic 4	Pic 5	Pic 6	Pic 7	Pic 8	Pic 9	Pic 10	Pic 11	Pic 12	Pic 13	Pic 14	Pic 15	Pic 16	Pic 17	Pic 18	Kirats
	metres	metres	metres	metres	metres	metres	metres	metres	metres	metres	metres	metres	metres	metres	metres	metres	metres	metres	metres	
0	−·84	−·30	·24	·78	1·32	1·86	2·40	2·94	3·48	**4·00**	4·56	5·10	5·64	6·18	6·72	7·26	7·80	8·34	8·88	0
1	−·82	−·28	·26	·80	1·34	1·88	2·42	2·97	**3·50**	4·03	4·58	5·12	5·66	6·20	6·74	7·28	7·82	8·36	8·90	1
2	−·80	−·25	·28	·82	1·37	1·91	2·45	**3·00**	3·52	4·06	4·60	5·14	5·68	6·22	6·76	7·30	7·84	8·38	8·92	2
3	−·78	−·23	·31	·85	1·39	1·93	2·47	3·02	3·55	4·08	4·63	5·17	5·71	6·25	6·79	7·33	7·87	8·41	8·94	3
4	−·75	−·21	·33	·87	1·41	1·95	**2·50**	3·04	3·57	4·11	4·65	5·19	5·73	6·27	6·81	7·35	7·89	8·43	8·96	4
5	−·73	−·19	·35	·89	1·43	1·97	2·52	3·06	3·59	4·13	4·67	5·21	5·75	6·29	6·83	7·37	7·91	8·45	8·98	5
6	−·71	−·17	·37	·92	1·45	**2·00**	2·54	3·08	3·61	4·16	4·70	5·24	5·77	6·31	6·85	7·39	7·93	8·48	**9·00**	6
7	−·68	−·14	·40	·94	1·47	2·02	2·56	3·10	3·64	4·18	4·72	5·26	5·80	6·34	6·88	7·42	7·96	**8·50**	9·03	7
8	−·66	−·12	·42	·96	**1·50**	2·04	2·58	3·12	3·66	4·20	4·74	5·28	5·82	6·36	6·90	7·44	7·98	8·52	9·06	8
9	−·64	−·10	·44	·98	1·52	2·06	2·60	3·14	3·68	4·22	4·76	5·30	5·84	6·38	6·92	7·46	**8·00**	8·54	9·08	9
10	−·61	−·08	·46	**1·00**	1·55	2·08	2·63	3·16	3·70	4·24	4·78	5·32	5·86	6·41	6·95	7·48	8·02	8·57	9·10	10
11	−·59	−·06	·48	1·02	1·57	2·11	2·65	3·19	3·73	4·27	4·81	5·35	5·89	6·43	6·97	**7·50**	8·05	8·59	9·13	11
12	−·57	−·04	**0·50**	1·05	1·59	2·13	2·67	3·21	3·75	4·29	4·83	5·37	5·91	6·45	**7·00**	7·53	8·07	8·61	9·15	12
13	−·55	−·02	·53	1·07	1·61	2·15	2·69	3·23	3·77	4·31	4·85	5·39	5·93	6·47	7·02	7·55	8·09	8·63	9·17	13
14	−·52	**0·00**	·55	1·09	1·63	2·17	2·71	3·25	3·79	4·33	4·88	5·42	5·96	**6·50**	7·04	7·58	8·11	8·65	9·19	14
15	**−·50**	·03	·58	1·12	1·66	2·20	2·74	3·28	3·82	4·36	4·90	5·44	5·98	6·52	7·06	7·60	8·14	8·68	9·22	15
16	−·48	·06	·60	1·14	1·68	2·22	2·76	3·30	3·84	4·38	4·92	5·46	**6·00**	6·54	7·08	7·62	8·16	8·70	9·24	16
17	−·46	·08	·62	1·16	1·70	2·24	2·78	3·32	3·86	4·40	4·94	5·48	6·02	6·56	7·10	7·64	8·18	8·72	9·26	17
18	−·44	·10	·65	1·18	1·73	2·26	2·81	3·35	3·88	4·42	4·96	**5·50**	6·04	6·58	7·13	7·66	8·20	8·74	9·29	18
19	−·41	·12	·67	1·21	1·75	2·29	2·83	3·37	3·90	4·44	4·98	5·53	6·07	6·60	7·15	7·69	8·23	8·77	9·31	19
20	−·39	·15	·69	1·23	1·77	2·31	2·85	3·39	3·92	4·46	**5·00**	5·55	6·09	6·63	7·17	7·71	8·25	8·79	9·33	20
21	−·37	·17	·71	1·25	1·79	2·33	2·87	3·41	3·94	4·48	5·03	5·57	6·11	6·65	7·19	7·73	8·27	8·81	9·35	21
22	−·35	·20	·74	1·27	1·82	2·35	2·90	3·43	3·96	**4·50**	5·05	5·60	6·14	6·68	7·21	7·75	8·29	8·83	9·37	22
23	−·32	·22	·76	1·30	1·84	2·38	2·92	3·46	3·98	4·53	5·08	5·62	6·16	6·70	7·24	7·78	8·32	8·86	9·40	23

APPENDIX V.

Cairo Gauge.

Kirats	Pics and kirats converted into metres, referred to zero at R.L. 12·50 metres																			Kirats
	Pic 8	Pic 9	Pic 10	Pic 11	Pic 12	Pic 13	Pic 14	Pic 15	Pic 16	Pic 17	Pic 18	Pic 19	Pic 20	Pic 21	Pic 22	Pic 23	Pic 24	Pic 25	Pic 26	
	metres	metres	metres	metres	metres	metres	metres	metres	metres	metres	metres	metres	metres	metres	metres	metres	metres	metres	metres	
0	·89	1·48	2·03	2·62	3·16	3·69	4·18	4·66	5·15	5·39	5·64	5·91	6·18	6·46	6·74	7·26	7·83	8·35	8·88	0
1	·91	**1·50**	2·05	2·65	3·18	3·71	4·20	4·68	5·16	5·40	5·65	5·92	6·19	6·47	6·76	7·28	7·85	8·37	8·91	1
2	·93	1·52	2·08	2·67	3·20	3·73	4·22	4·70	5·17	5·41	5·66	5·93	6·20	6·48	6·78	7·31	7·87	8·39	8·93	2
3	·95	1·54	2·10	2·70	3·22	3·75	4·24	4·72	5·18	5·42	5·67	5·94	6·21	6·49	6·80	7·35	7·89	8·41	8·95	3
4	·97	1·56	2·13	2·72	3·24	3·77	4·26	4·74	5·19	5·43	5·68	5·96	6·23	**6·50**	6·83	7·37	7·91	8·43	8·97	4
5	**1·00**	1·59	2·15	2·74	3·27	3·79	4·28	4·76	5·20	5·44	5·69	5·97	6·24	6·51	6·85	7·39	7·93	8·46	**9·00**	5
6	1·02	1·61	2·18	2·76	3·29	3·82	4·30	4·78	5·21	5·45	5·70	5·98	6·25	6·52	6·87	7·41	7·96	8·48	9·02	6
7	1·05	1·63	2·21	2·78	3·31	3·84	4·32	4·80	5·22	5·46	5·71	5·99	6·26	6·53	6·89	7·43	7·98	**8·50**	9·04	7
8	1·07	1·65	2·24	2·80	3·34	3·86	4·34	4·82	5·23	5·47	5·72	**6·00**	6·27	6·54	6·91	7·46	**8·00**	8·52	9·06	8
9	1·09	1·67	2·26	2·82	3·37	3·88	4·36	4·84	5·24	5·48	5·74	6·01	6·28	6·56	6·93	7·48	8·02	8·54	9·09	9
10	1·11	1·69	2·29	2·84	3·39	3·90	4·38	4·86	5·25	5·49	5·75	6·02	6·29	6·57	6·96	**7·50**	8·04	8·56	9·11	10
11	1·13	1·72	2·31	2·86	3·41	3·92	4·40	4·88	5·26	**5·50**	5·76	6·03	6·31	6·58	6·98	7·52	8·06	8·59	9·13	11
12	1·15	1·74	2·33	2·88	3·43	3·94	4·42	4·90	5·27	5·51	5·77	6·04	6·32	6·59	**7·00**	7·54	8·09	8·61	9·15	12
13	1·17	1·76	2·35	2·90	3·46	3·96	4·44	4·92	5·28	5·52	5·78	6·05	6·33	6·61	7·02	7·56	8·11	8·63	9·18	13
14	1·20	1·78	2·37	2·93	3·48	3·98	4·46	4·94	5·29	5·53	5·79	6·07	6·34	6·62	7·04	7·59	8·13	8·65	9·20	14
15	1·22	1·81	2·39	2·95	**3·50**	**4·00**	4·48	4·96	5·30	5·54	5·80	6·08	6·35	6·63	7·06	7·61	8·15	8·68	9·22	15
16	1·25	1·83	2·42	2·97	3·52	4·02	**4·50**	4·98	5·31	5·55	5·81	6·09	6·36	6·64	7·09	7·63	8·17	8·70	9·24	16
17	1·28	1·86	2·45	**3·00**	3·54	4·04	4·52	**5·00**	5·32	5·57	5·83	6·10	6·37	6·65	7·11	7·66	8·20	8·72	9·26	17
18	1·31	1·88	2·48	3·02	3·56	4·06	4·54	5·02	5·33	5·58	5·84	6·12	6·39	6·66	7·13	7·68	8·22	8·74	9·29	18
19	1·34	1·91	**2·50**	3·04	3·58	4·08	4·56	5·04	5·34	5·59	5·85	6·13	6·40	6·68	7·16	7·71	8·24	8·76	9·31	19
20	1·37	1·94	2·52	3·06	3·60	4·10	4·58	5·06	5·35	5·60	5·87	6·14	6·41	6·69	7·18	7·73	8·26	8·79	9·33	20
21	1·40	1·96	2·55	3·09	3·62	4·12	4·60	5·09	5·36	5·61	5·88	6·15	6·42	6·70	7·20	7·75	8·29	8·81	9·35	21
22	1·42	1·98	2·57	3·11	3·64	4·14	4·62	5·11	5·37	5·62	5·89	6·16	6·43	6·71	7·22	7·78	8·31	8·83	9·37	22
23	1·45	**2·00**	2·60	3·13	3·66	4·16	4·64	5·13	5·38	5·63	5·90	6·17	6·44	6·73	7·24	7·80	8·33	8·85	9·40	23

APPENDIX VI.

TABLE FOR CONVERTING CUBIC METRES PER DAY INTO CUBIC METRES PER SECOND.

Cubic metres per day	Cubic metres per second	Cubic metres per day	Cubic metres per second	Cubic metres per day	Cubic metres per second
10,000	0·1157	750,000	8·6805	**5,000,000**	**57·8704**
20,000	0·2315	800,000	9·2593	5,250,000	60·7639
30,000	0·3472	850,000	9·8380	5,500,000	63·6574
40,000	0·4630	900,000	10·4167	5,750,000	66·5509
50,000	0·5787	950,000	10·9954	6,000,000	69·4444
60,000	0·6944	**1,000,000**	**11·5741**	6,250,000	72·3380
70,000	0·8102	1,250,000	14·4676	6,500,000	75·2315
80,000	0·9259	1,500,000	17·3611	6,750,000	78·1250
90,000	1·0417	1,750,000	20·2546	7,000,000	81·0185
100,000	**1·1574**	2,000,000	23·1481	7,250,000	83·9120
150,000	1·7361	2,250,000	26·0417	7,500,000	86·8055
200,000	2·3148	2,500,000	28·9352	7,750,000	89·6991
250,000	2·8935	2,750,000	31·8287	8,000,000	92·5926
300,000	3·4722	3,000,000	34·7222	8,250,000	95·4861
350,000	4·0509	3,250,000	37·6157	8,500,000	98·3796
400,000	4·6296	3,500,000	40·5092	8,750,000	101·2731
450,000	5·2083	3,750,000	43·4028	9,000,000	104·1667
500,000	**5·7870**	4,000,000	46·2963	9,250,000	107·0602
550,000	6·3657	4,250,000	49·1898	9,500,000	109·9537
600,000	6·9444	4,500,000	52·0833	9,750,000	112·8472
650,000	7·5231	4,750,000	54·9768	10,000,000	115·7407
700,000	8·1018				

ROUGH WORKING APPROXIMATIONS.

Cubic metres per day	Cubic metres per second	Cubic metres per day	Cubic metres per second	Cubic metres per day	Cubic metres per second
125,000	1·5	2,000,000	24	7,000,000	84
250,000	3	3,000,000	36	8,000,000	96
500,000	6	4,000,000	48	9,000,000	108
750,000	9	5,000,000	60	10,000,000	120
1,000,000	12	6,000,000	72		

APPENDIX VII.

TABLE FOR CONVERTING CUBIC METRES PER SECOND INTO CUBIC METRES PER DAY.

Cubic metres per second	Cubic metres per day	Cubic metres per second	Cubic metres per day	Cubic metres per second	Cubic metres per day	Cubic metres per second	Cubic metres per day
1	86,400	26	2,246,400	51	4,406,400	76	6,566,400
2	172,800	27	2,332,800	52	4,492,800	77	6,652,800
3	259,200	28	2,419,200	53	4,579,200	78	6,739,200
4	345,600	29	2,505,600	54	4,665,600	79	6,825,600
5	432,000	30	2,592,000	55	4,752,000	80	6,912,000
6	518,400	31	2,678,400	56	4,838,400	81	6,998,400
7	604,800	32	2,764,800	57	4,924,800	82	7,084,800
8	691,200	33	2,851,200	58	5,011,200	83	7,171,200
9	777,600	34	2,937,600	59	5,097,600	84	7,257,600
10	864,000	35	3,024,000	60	5,184,000	85	7,344,000
11	950,400	36	3,110,400	61	5,270,400	86	7,430,400
12	1,036,800	37	3,196,800	62	5,356,800	87	7,516,800
13	1,123,200	38	3,283,200	63	5,443,200	88	7,603,200
14	1,209,600	39	3,369,600	64	5,529,600	89	7,689,600
15	1,296,000	40	3,456,000	65	5,616,000	90	7,776,000
16	1,382,400	41	3,542,400	66	5,702,400	91	7,862,400
17	1,468,800	42	3,628,800	67	5,788,800	92	7,948,800
18	1,555,200	43	3,715,200	68	5,875,200	93	8,035,200
19	1,641,600	44	3,801,600	69	5,961,600	94	8,121,600
20	1,728,000	45	3,888,000	70	6,048,000	95	8,208,000
21	1,814,400	46	3,974,400	71	6,134,400	96	8,294,400
22	1,900,800	47	4,060,800	72	6,220,800	97	8,380,800
23	1,987,200	48	4,147,200	73	6,307,200	98	8,467,200
24	2,073,600	49	4,233,600	74	6,393,600	99	8,553,600
25	2,160,000	50	4,320,000	75	6,480,000	100	8,640,000

APPENDIX VIII.

DETAILS OF EXISTING WORKS IN UPPER AND LOWER EGYPT.

Name of Work	Assuân	Kena	Sohag	Assiout, S.	Assiout, N.	Minia	Beni-Suef	Geeza	Fayûm	Total, Upper Egypt	Behêra	Menoufia	Garbia	Kalyubia	Sharkia	Dakalia	Ismailia Canal	Total, Lower Egypt	Total, Egypt
	kils.	kils.	kils.	kils.	kils.	kils.	kils.	kils.	kils.	kils.	kils.	kils.	kils.	kils.	kils.	kils.	kils.	kils.	kils.
Nile banks	41	350	229	163	142	188	85	211	..	1409	220	172	288	59	1	180	..	920	2329
Basin banks	15	666	789	179	143	329	148	612	..	2881	..	..	..	..	..	..	..	..	2881
Basin canals	205	1063	910	349	102	180	134	405	..	3348	..	..	..	..	..	..	..	..	3348
Basin drains	8	57	65	71	67	..	45	..	..	313	..	..	..	..	..	..	..	..	313
Perennial canals	..	..	..	..	339	427	278	..	1153	2197	1360	1383	2677	679	2117	1478	316	10010	12207
Perennial drains	..	..	..	..	..	218	108	..	333	659	477	..	1100	..	267	768	57	2669	3328
	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.
Basin escapes	7	23	13	15	14	6	19	5	..	102	..	..	..	..	..	..	..	..	102
Basin regulators	15	200	125	48	41	21	11	29	..	490	..	..	..	..	..	..	..	..	490
Basin syphons	..	17	11	3	1	2	3	3	..	40	..	..	..	..	..	..	..	..	40
Perennial escapes	..	..	..	..	19	5	19	..	..	43	3	3	1	..	..	..	..	7	50
Perennial regulators	..	..	..	..	6	79	38	..	59	182	155	164	216	65	141	179	23	943	1125
Perennial syphons	..	..	..	..	..	6	3	..	..	9	46	4	30	..	23	22	1	126	135

APPENDIX IX.

DETAILS OF WATER-LIFTING MACHINES IN UPPER EGYPT.

Province	Fixed Engines										Portable Engines										Water Wheels (Sakyas)					
	On the Nile		On Canals		On the Ibrahimia Canal		On the Bahr Yusuf		Total		On the Nile		On Canals		On the Ibrahimia Canal		On the Bahr Yusuf		Total		On the Nile	On Canals	On the Ibrahimia Canal	On the Bahr Yusuf	On Wells in the Basins	Total
	No.	H.P.	No.	H.P.	No.	H.P.	No.	H.P.	No.	H.P.	No.	H.P.	No.	H.P.	No.	H.P.	No.	H.P.	No.	H.P.	No.	No.	No.	No.	No.	No.
Assuân .	3	64	..	..	..	..	..	..	3	64	..	..	..	..	..	..	..	..	..	..	860	..	..	..	530	1390
Kena .	10	860	..	..	..	..	..	..	10	860	5	60	..	..	..	..	..	..	5	60	2720	..	..	..	7320	10040
Sohag .	7	193	..	..	..	..	..	..	7	193	11	164	..	..	..	..	..	..	11	164	15	..	..	..	5300	5315
Assiout, S.	5	107	..	..	..	..	..	..	5	107	1	10	..	..	..	..	..	..	1	10	5	..	..	..	3020	3025
Assiout, N.	8	540	..	..	14	213	3	37	25	790	1	16	..	..	3	52	3	32	7	100	5	..	320	360	400	1085
Minia .	5	455	..	..	..	..	7	80	12	535	3	36	..	..	11	138	13	120	27	294	50	..	30	420	120	620
Beni-Suef .	3	62	..	..	..	..	2	28	5	90	3	42	..	..	..	..	6	64	9	106	10	..	60	640	50	760
Geeza .	21	1074	4	66	..	..	..	..	25	1140	35	346	2	18	..	..	..	..	37	364	280	80	..	..	600	960
Fayûm .	..	..	3	42	..	..	..	..	3	42	..	..	6	76	..	..	..	..	6	76	..	1050	..	..	..	1050
Total .	62	3355	7	108	14	213	12	145	95	3821	59	674	8	94	14	190	22	216	103	1174	3945	1130	410	1420	17340	24245

The H.P.'s are the ordinary nominal H.P.'s of commerce, approximating half the indicated H.P.

APPENDIX X.

DETAILS OF WATER-LIFTING MACHINES IN LOWER EGYPT.

Province	Fixed Engines								Portable Engines								Water Wheels (Sakyas)				
	On the Damietta Branch		On the Rosetta Branch		On Canals		Total		On the Damietta Branch		On the Rosetta Branch		On Canals		Total		On the Damietta Branch	On the Rosetta Branch	On Canals	On Wells in the Fields	Total
	No.	H.P.	No.	H.P.	No.	H.P.	No.	H.P.	No.	H.P.	No.	H.P.	No.	H.P.	No.	H.P.	No.	No.	No.	No.	No.
Behêra	..	..	12	564	42	640	54	1204	..	..	33	294	543	4750	576	5044	..	100	7800	20	7920
Menoufia	1	40	8	180	69	1004	78	1224	7	52	10	116	612	5240	629	5408	400	600	9200	4000	14200
Garbia	51	750	4	70	148	2097	203	2917	96	936	22	186	1023	9331	1141	10453	900	600	13300	1000	15800
Kalyubia	2	40	..	..	51	552	53	592	19	216	..	..	167	1452	186	1668	210	..	1910	4200	6320
Sharkia	..	..	..	..	21	385	21	385	..	..	..	..	302	2727	302	2727	..	..	13000	4000	17000*
Dakalia	40	553	..	..	65	694	105	1247	49	456	..	..	326	2013	375	2469	900	..	13900	2800	17600*
Ismailia canal	..	..	..	..	13	283	13	283	..	..	..	..	41	385	41	385	..	..	350	1420	1770
Total	94	1383	24	814	409	5655	527	7852	171	1660	65	596	3014	25898	3250	28154	2410	1300	59460	17440	80610

The H.P.'s are the ordinary nominal H.P.'s of commerce, approximating half the indicated HP.

* Very few of these water wheels are working to-day.

APPENDIX XI.

DETAILS OF SUMMER AND FLOOD CROPS IN THE BASIN TRACTS.

If the areas recorded on pages 93 to 101, as under summer and flood crops in the basins of Upper Egypt during the high flood year 1898 be added together, the totals will work out as follows :—

Province	Total Area in Basins	Cotton	Sugar Cane	Summer Sorghum	Flood Sorghum	Remarks
	acres	acres	acres	acres	acres	
Assuân .	19,800	..	..	1,000	7,000	During years of low flood the areas under flood sorghum are very considerably increased.
Kena .	286,600	..	10,000	23,000	27,000	
Sohag .	275,500	..	3,500	29,000	20,000	
Assiout .	363,800	..	3,500	35,000	11,000	
Minia .	208,000	2,000	4,000	4,000	8,000	
Beni-Suef	175,790	6,000	..	8,000	1,000	
Geeza .	105,600	3,000	4,000	13,000	8,000	
Total .	1,435,000	11,000	25,000	113,000	82,000	

In addition to the above are the areas of summer and flood crops sown on the Nile berms and islands. The areas of Nile berms and islands are given in detail on page 23, and on these the area of flood sorghum which is sown depends entirely on the flood. In an ordinary flood the following areas may be considered fairly representative :—

Province	Area of Nile Berms and Islands	Flood Sorghum and Maize
	acres	acres
Assuân . .	53,700	20,000
Kena. . .	56,300	50,000
Sohag . .	49,500	20,000
Assiout . .	24,900	8,000
Minia . .	33,000	14,000
Beni-Suef . .	8,900	3,000
Geeza . .	70,500	35,000
Total . .	296,800	150,000

INDEX.

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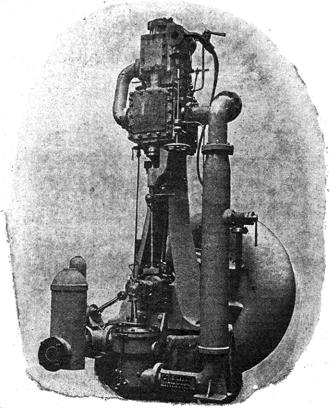
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"(*Signed*) E. MONNERAT."

"*14th April*, 1895.

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"(*Signed*) M. N. WHITE."

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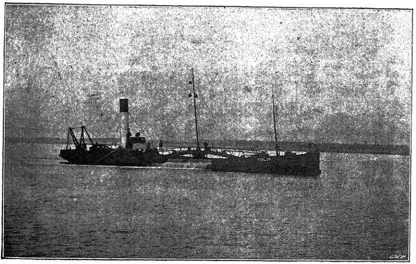
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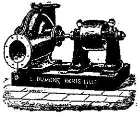
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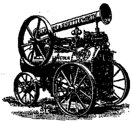
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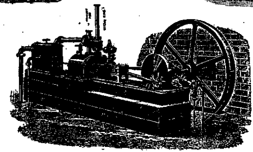
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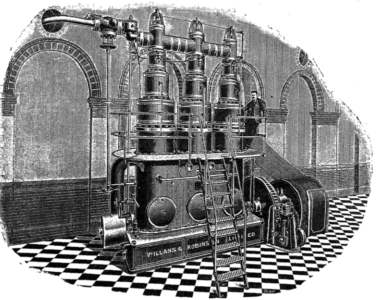
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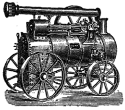
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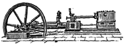
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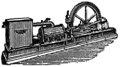


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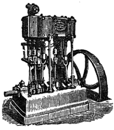
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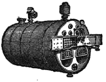
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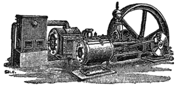
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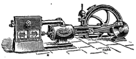
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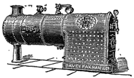
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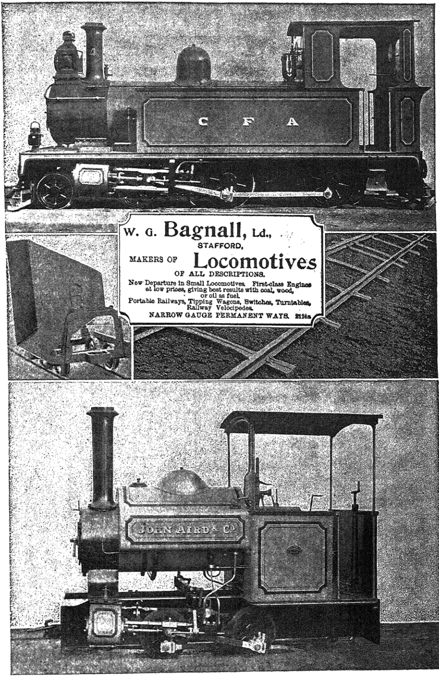
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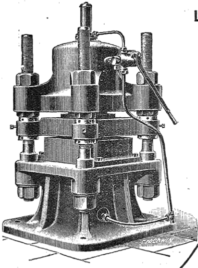
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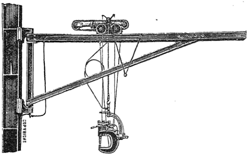
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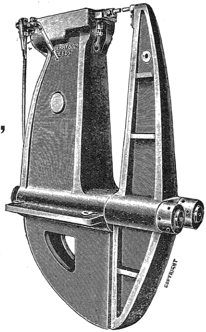
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Diameter of Cylinder	2	$2\frac{1}{2}$	3	$3\frac{3}{8}$	$4\frac{1}{2}$	$5\frac{1}{4}$	$5\frac{1}{2}$	7
Length of Stroke	2	$2\frac{1}{2}$	3	4	5	6	6	6
Galls. per hour	60	125	210	440	660	1000	1080	1280
N.H.P. of Boiler	4	8	16	30	45	70	72	80

Sizes.	DOUBLE ACTION.					
	No. 3.	No. 4.	No. 5.	No. 6.	No. 7.	No. 8.
Diameter of Ram	$1\frac{1}{2}$	2	$2\frac{1}{2}$	3	$3\frac{1}{2}$	5
Diameter of Cylinder	3	$3\frac{3}{4}$	$4\frac{1}{2}$	$5\frac{1}{2}$	6	7
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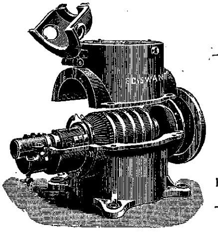
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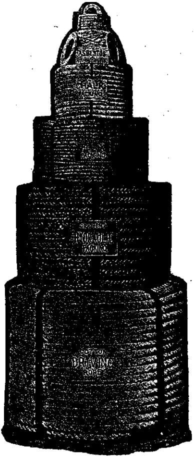
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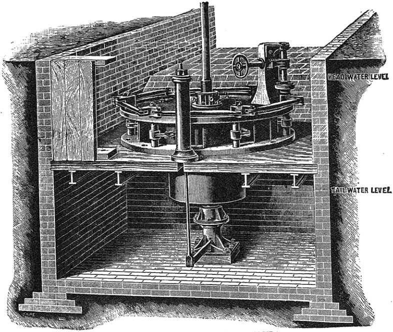
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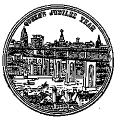
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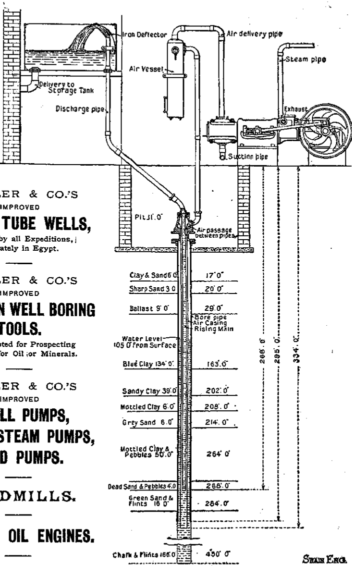
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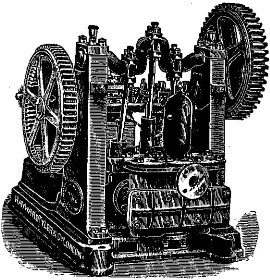
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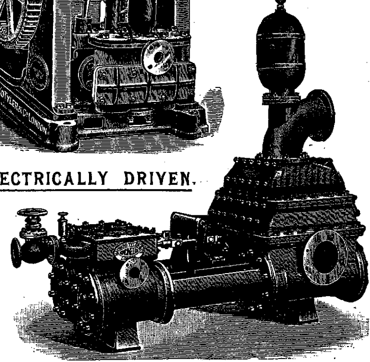
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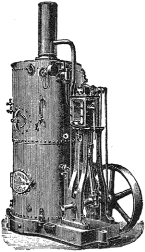
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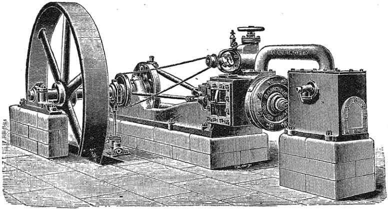
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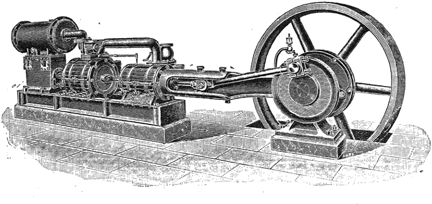
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